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Studies on Age and Growth, Reproduction, and Population Dynamics of Red Gurnard, *Chelidonichthys kumu* (Lesson and Garnot), in the Hauraki Gulf, New Zealand

By

R. D. Elder

Fisheries Research Division
New Zealand Ministry of Agriculture and Fisheries

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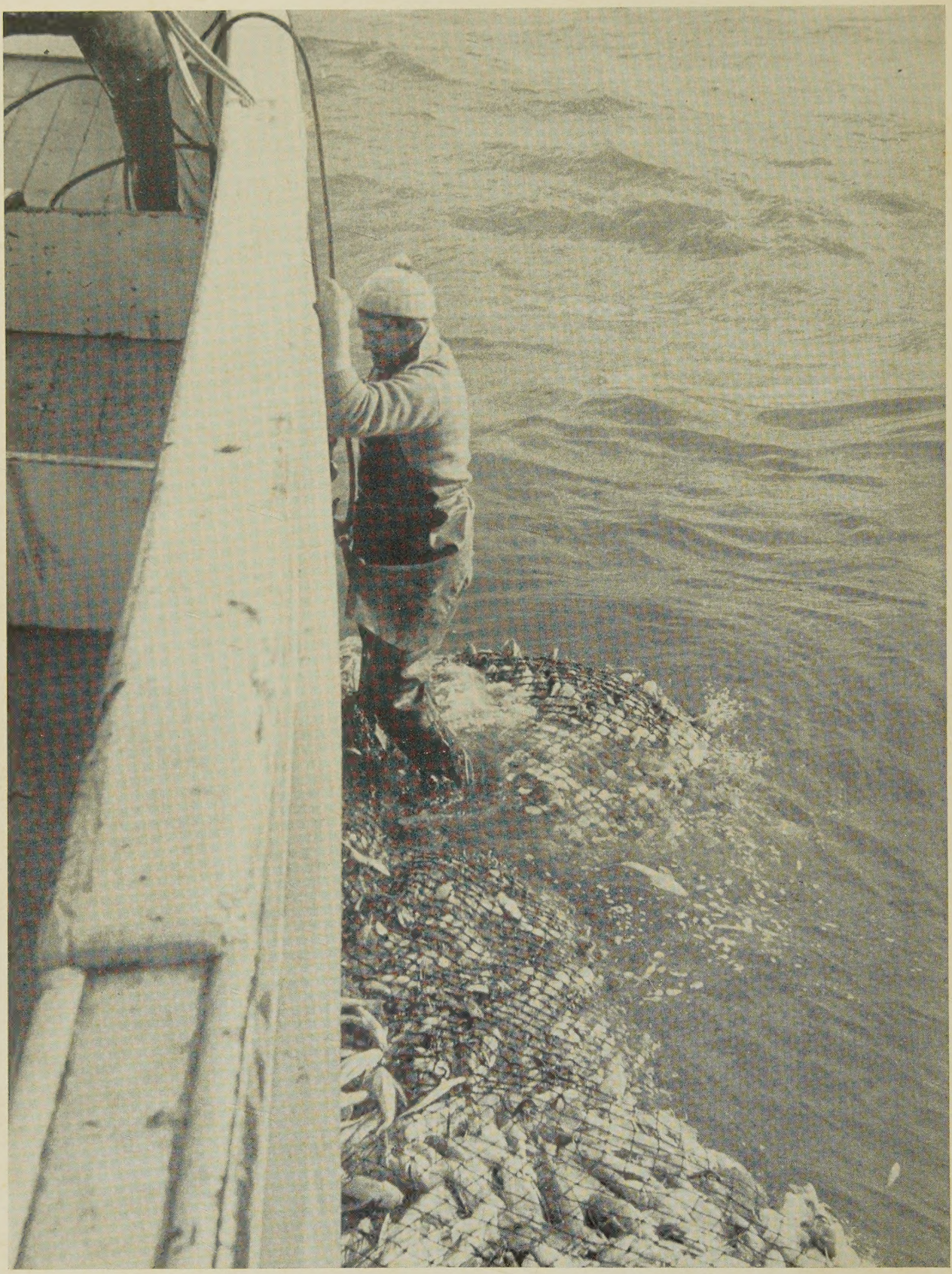

Frontispiece: Splitting the bag of an exceptional catch of red gurnard.

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FOREWORD

BEFORE best use can be made of the various stocks of commercial fishes in New Zealand waters some understanding is needed of the basic biology and behaviour of the species concerned. At the same time development of a fishery or the maintenance of the stocks on which an industry depends requires proper appreciation of the resources and how they may be affected by fishing.

Red gurnard is of major local commercial significance, and Dr Elder not only deals with aspects of the biology and behaviour of the species, but interprets these in terms of the fishery of the Hauraki Gulf. In so doing he draws attention to the importance of the migratory behaviour of the fish and to the fact that current management measures preclude optimum use of the resource. This, in turn, means that the stocks are protected from overexploitation.

G. DUNCAN WAUGH,

Director, Fisheries Research Division.

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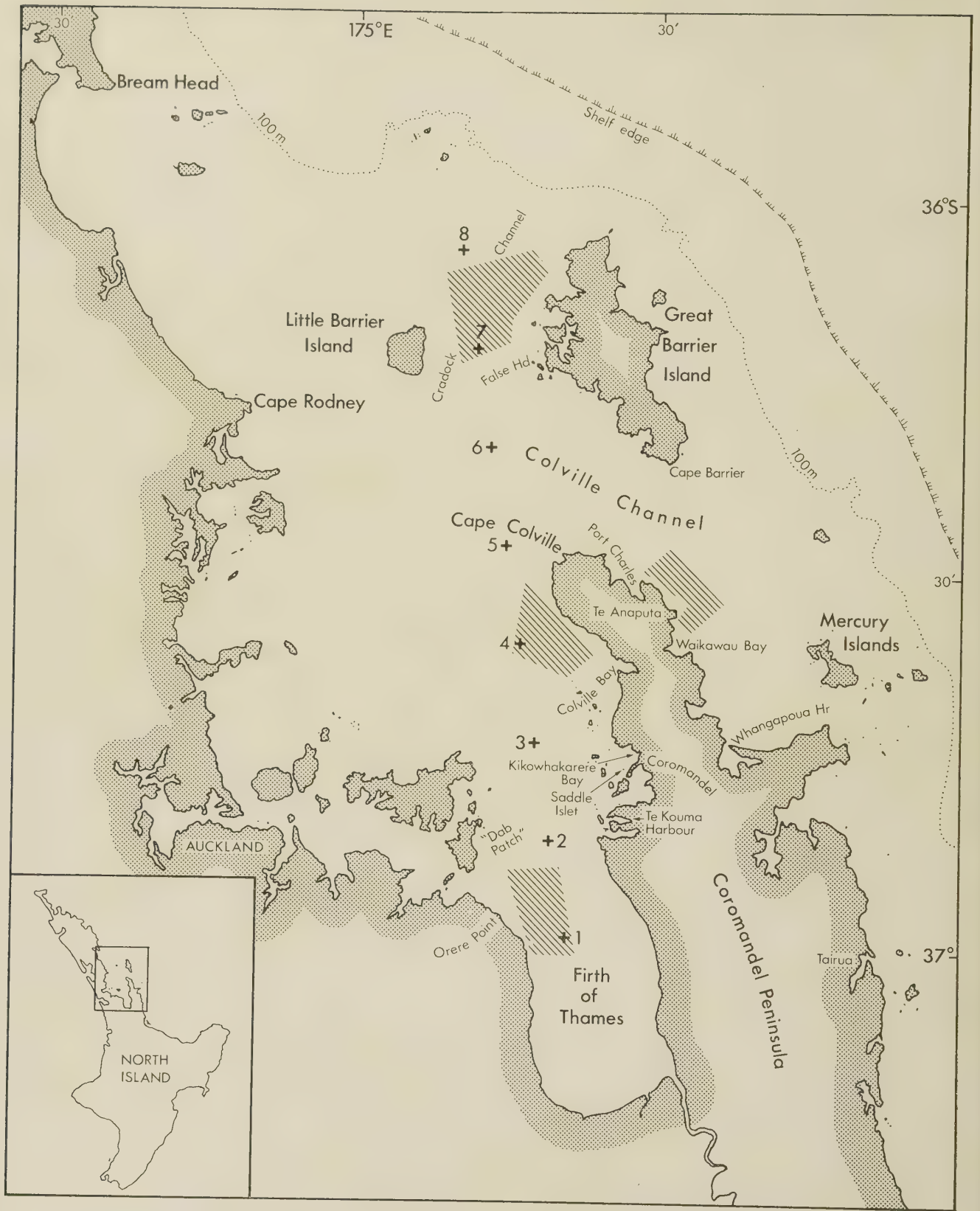


Fig. 1: The Hauraki Gulf, showing the positions of the sampling areas (hatched). The hydrographic stations are numbered from 1 to 8 from the Firth of Thames to Cradock Channel and are marked with crosses. The seaward limit of the Gulf is shown by the 100-m contour (dotted line).

INTRODUCTION

The red gurnard, *Chelidonichthys kumu* (Lesson and Garnot, 1826), is found throughout the central tropical and temperate Indo-Pacific coastal waters, including South Korea, China, Japan, Malaysia, South Africa, Australia, and New Zealand (J. L. B. Smith 1953, Scott 1962, Okada 1966). It is well known for the striking coloration of its large, wing-like pectoral fins and the modification of the first three pectoral fin rays into walking "legs".

The New Zealand distribution of red gurnard includes all the coastal waters of both the North and South Islands, except the southern fiords, and especially on mud, sand, and sandy-shell bottom types, but excluding rock. Red gurnard is most common in shallow coastal waters, the best commercial catches being taken in depths down to 55 m; it is less common in depths between 55 m and 85 m, and it sometimes occurs in depths as great as 180 m.

Red gurnard ranked fourth in total landings and seventh in total value among the main commercial wet fish species for New Zealand for the calendar year ended 31 December 1970, with a total landing of 3719 tonnes valued at $NZ 359 583 (New Zealand Marine Department 1971). Most (90%) of the New Zealand landings of red gurnard are taken by otter trawl. A small quantity (5%) is caught by Danish seine and the remainder by lines and other nets.

Only limited information has been published on the red gurnard in New Zealand waters. Anderton (1907) described the eggs and early development of the larvae. Staples (1967, 1971) studied age determination and growth based on samples taken from Pegasus Bay, South Island. Shuntov (1970), in a paper on the seasonal occurrence of shelf fishes in the New Zealand area, noted that the main concentrations of *Chelidonichthys kumu* lie north of the zone of Subtropical Convergence.

Japanese authors have published several works on the red gurnard (local name: hobo). Furukawa and Ikeda (1953) studied stomach contents and some aspects of the reproduction of five species of gurnard, including *Chelidonichthys kumu,* in the Hyuga Nada (off the east and south-east coasts of Kyushu Island). Vertebrae were used by Yunokawa (1961) to age red gurnard from Japanese waters in his account of age and growth. An investigation of local groups of *C. kumu,* based on morphometric characters and fisheries statistics, in the East China and Yellow Seas area was made by Nakashima and Kojima (1962). They found three self-supporting groups in the area and noted that migration occurred in two of the groups; at least one of these migrations was shown to be related to spawning behaviour. They also found that to some extent the sexes could be distinguished on the basis of head size and thickness of cheeks. Mito (1963) described the eggs and early larvae of *C. kumu* in Japanese waters.

The taxonomic status of Northern and Southern Hemisphere red gurnard of the genus *Chelidonichthys* was discussed by Ochiai and Okada (1966). They concluded that the two forms represent distinct species, the northern species being *Chelidonichthys spinosus* (McLelland), distributed from the South China Sea to Po Hai (Yellow Sea) and the northern parts of Japan, and the southern species being *Chelidonichthys kumu* (Lesson and Garnot), widely distributed in the Southern Hemisphere from New Zealand westwards to the east coast of South Africa.

Ochiai and Okada recognised the two species by differences in pectoral fin markings, size and shape of humeral spines, and relative size of some body parts, especially the eye. The only meristic difference they found was in the numbers of spinous shields developed along the base of the dorsal fin. However, the variation they found was matched by Nakashima and Kojima (1962) in their study of local groups in the East China and Yellow Seas. I therefore question the validity of recognising two species and suggest that the variations noted by Ochiai and Okada might be explained in terms of a cline.

The present study is based on fish taken from the Hauraki Gulf (Fig. 1) and examines some aspects of the biology of the species relevant to future management of the fishery in that area. In particular, age determination, age and growth, population structure, mortality, length-weight relationships and condition, and reproductive behaviour are considered. Finally, yield per recruit estimates are derived and management implications drawn.

STUDY AREA

The Hauraki Gulf lies on the north-east coast of the North Island of New Zealand between about 35° 50′ S (Bream Head) and 37° 13′ S (the southern shore of the Firth of Thames). To the east the 100-m contour is accepted as its boundary, extending from Bream Head in the north to the Mercury Islands in the south-east (at about 36° 38′ S) (Fig. 1).

As described by Paul (1968), the area may be divided into the "inner Gulf"—the area of water lying south of a line from Cape Rodney to Cape Colville—and the "outer Gulf"—the area outside the Rodney-Colville line but inside the 100-m contour. The inner Gulf covers about 3900 km², of which 200 km² are shallow tidal harbours, 1600 km² are waters less than 20 m deep, 1100 km² lie between the 20-m and 40-m contours, and 1000 km² are deeper than 40 m. The outer Gulf covers about 5400 km², mostly between 40 m and 100 m deep.

The whole area is liberally scattered with islands and island groups. The western and southern coastlines are deeply indented with bays and harbours, and the sea floor generally shelves gradually to the 20-m contour. On the north-eastern side the sea floor drops steeply to the 40-m contour.

SAMPLING AREAS

Four sampling areas (Fig. 1) were chosen to provide information on red gurnard from as wide a variety of ecological situations as the species inhabits within the Hauraki Gulf. Two of these areas are in the inner Gulf and two in the outer Gulf.

The inner Gulf areas are:

1. The **Firth of Thames** sampling area, lying to the east of Orere Point with a depth range of 9 to 26 m (5 to 14 fm) and a soft mud bottom.

2. The **Colville** sampling area, lying to the north-west of Colville Bay with a depth range of 15 to 44 m (8 to 24 fm) and a bottom of mostly hard mud and shell.

The outer Gulf areas are:

1. The **Te Anaputa** sampling area, lying to the east of Port Charles and Te Anaputa with a depth range of 29 to 51 m (16 to 28 fm) and a bottom of hard sand and shell.

2. The **Cradock Channel** sampling area, in Cradock Channel, between Little Barrier Island and Great Barrier Island, with a depth range of 51 to 79 m (28 to 43 fm) and a bottom of hard mud.

SAMPLING METHOD

Samples of the gurnard population from each of the four sampling areas were taken between December 1968 and March 1970 at intervals as close to 1 month as practicable. Two vessels were used for the work—the fisheries research trawler *Ikatere* of 19.2 m (63 ft) overall length and 113 kW (152 bhp) and the fishing vessel *Cobra* of 15.2 m (50 ft) overall length and 82 kW (110 bhp), which was chartered during August 1969. Otter trawl nets with 10.2-cm (4-in.)-mesh cod-end and 3.8-cm (1.5-in.)-mesh cod-end liners were used by both vessels. Mesh measurements were made between opposite knots, inside the knots, with the mesh stretched.

Juvenile red gurnard were sought in various locations with a prawn trawl and two sizes of beam trawl (one with a 2-m beam and one with a 4-m beam), all with fine mesh. The beam trawls graded to a 1.9-cm (0.75-in.)-mesh cod-end, and the prawn trawl had a 5.1-cm (2-in.)-mesh cod-end with a 2.5-cm (1-in.)-mesh cod-end liner.

A hydrographic transect of 56 nautical miles with eight equidistant stations along it from the Firth of Thames to the outer end of Cradock Channel (Fig. 1) was also worked during each monthly cruise. The following information was collected at each station:

1. Surface water temperature, with a bucket and paired thermometers graduated to 0.1°C.
2. Temperature profile from surface to bottom, by use of a Brown Mk IS 55-m bathythermograph for the shallow stations and a Mk I 140-m bathythermograph for the deeper stations. The bathythermographs were calibrated to surface temperature from readings of the paired thermometers.

The age composition for each sex, by month and area, was estimated by stratifying the population by length groups and sampling for age composition and sex ratio. This method has been used previously by Ketchen (1950), Gulland (1955), Pinhorn and Fleming (1965), and Raitt (1968).

After a trial survey and consideration of the comments of the above authors and the length of time needed to process the catch the following procedure was adopted.

The fork length of all fish in a catch was measured, except on three occasions—Colville, April and July 1969, and Firth of Thames, August 1969—when the large size of the catches necessitated only a random sample of the whole catch being measured. These occasions are allowed for in the later catch rate calculations. Fork length measurements were made to the nearest whole centimetre below the actual length.

Next, within each 1-cm length group the first 15 fish were sexed and the first three females and three males were aged. Midway through the 16-month sampling period it was found that more otoliths could conveniently be collected and processed for age determination and so the number of fish in each group was increased to five. If there were fewer than 15 fish in a length group, all fish in the group were sexed, and similarly if there were fewer than three fish (later five) of a particular sex within a length group, all were aged.

Though the theory of stratified random sampling as applied to fisheries is discussed by Gulland (1955), the essential equations are repeated here for convenience:

The total number of individuals of each sex in a sample was found by adding the contributions from each length group. Thus, if N_i fish of the ith length group were sampled and n_i of them were examined for sex, among which $n_i p_i$ were of a certain sex, then:

p_i = proportion of given sex in the ith length group.

$N_i p_i$ = number of given sex in the length group in the whole sample.

If N_p was the total number in the whole sample, $N_p = \Sigma N_i p_i$.

The total number of fish of each age group per sex in a sample was found by adding the contributions from each length group. Thus, if N_j $(= N_i p_i)$ fish of one sex of the ith length group were sampled, and a total of n_j of them were examined for age, among which $n_j p_j$ were of a certain age, then:

p_j = proportion of given age in the ith length group.

$N_j p_j$ = number of given age in the length group in the whole sample.

If N_q was the estimated total number of any age of each sex in the whole sample, then:

$$N_q = \Sigma N_j p_j$$

Five fish of each sex in each 1-cm length group, if available in the sample, were also examined for stage of gonad maturity (see the section "Reproduction"). With the sexes kept separate, the five fish were grouped as virgin or sexually mature, and the proportion of each category in the 1-cm length group was applied to the total number in the length group to

determine the total number of virgin and mature fish in each 1-cm length group. Then the numbers of virgin and the numbers of sexually mature fish were summed over all length groups, which provided the total number of virgin and the total number of sexually mature fish in the whole sample.

This is the same theory as in the above equations, but is limited to two categories only—virgin and sexually mature.

The fraction of each post-virgin gonad stage among the sexually mature portion of the sample was then determined. The total number of sexually mature fish in the catch was then multiplied by each of these fractions in turn to provide the total number of fish at each stage of gonad maturity.

Thus, if N_m was the total number of sexually mature fish in the catch, n_m was the number of sexually mature fish in the sample, and n_i was the number of fish of gonad stage i in the sample, then N_{mi}, the total number of gonad stage i in the catch, is given by:

$$N_{mi} = \frac{N_m . n_i}{n_m}$$

For the study of length-weight relationships, five females and five males in each 1-cm length group (or all present if there were fewer than five in the group) were gutted and weighed. All organs in the body cavity, from the oesophagus to the anus, were removed when gutting, including the gonads, which were weighed separately.

Fish over 50 g were weighed on a Salter Duet pan-type spring balance graduated in 10-g divisions from 0 to 500 g and in 25-g divisions from 500 g to 5 kg. The balance was accurate within the range of $\pm$ 1 division in each scale. Though lacking in fine precision, this balance was the most suitable for use at sea of those available and as accurate as could be used aboard a vessel lying at anchor. It could be read to $\pm$ 0.5 division. Fish less than 50 g, and gonads, were weighed on a Salter laboratory-type spring balance graduated in 0.5-g divisions. This balance was accurate to $\pm$ 0.25 g and could be accurately read to $\pm$ 1 division aboard a vessel at anchor.

OTOLITHS AND AGE DETERMINATION

INTRODUCTION

Age determination of fish from otoliths is based on the theory that fluctuations in growth rate are reflected in the composition of the otoliths. Studies on many species have shown such fluctuations to be annual. Changes in composition of the otoliths are visible as zones with different optical densities. It has been established that such differences are caused by changes in the proportion of calcium carbonate (aragonite) and protein (conchiolin) content laid down in the zones during growth (Dannevig 1956, Irie 1955, 1957, 1960).

The zones are termed "opaque zones" or "hyaline zones" depending on whether they block or pass light. The appearance of the zones through a microscope depends on the nature of the light with which they are illuminated. When viewed with reflected light (that is, light shone from above) the opaque zones appear light coloured and the hyaline zones dark, and with transmitted light (that is, light shone from the side or below) the opaque zones appear dark and the hyaline light. Much confusion appears to have been caused by authors not defining the nature of the light used.

PREPARATION OF OTOLITHS

In this study several techniques used by other workers for the preparation of otoliths were tried before a quick and satisfactory method was found for reliable interpretation of growth zones (see Graham 1929, Chugunova 1959, Christensen 1964, Albrechtsen 1968, Raitt 1968, S. W. Smith 1968, Ketchen 1970). At first the otoliths were examined whole, immersed in a variety of high refractive index media, including beechwood creosote, xylene, glycerine, cedarwood oil, and microscope immersion oil. Some otoliths could be interpreted with one or more of these media, but generally the method was unsatisfactory. In later tests whole otoliths were heated and examined as above, but the results were similar to those from unheated otoliths except for an increase in contrast, which occasionally was advantageous. However, Staples (1971) found that heated whole otoliths, viewed under xylene with reflected light, were successful and gave consistent results for ageing red gurnard collected from Pegasus Bay, east coast of the South Island.

In subsequent trials the otolith was cut or broken transversely. As the longitudinal sulcus in a red gurnard otolith is deep, the otolith had to be mounted in supporting material for successful sectioning. Both heated and unheated otoliths were therefore mounted in polyester resin and sectioned with a small fine-toothed saw. The cut surface was then smoothed on various grades of fine wet and dry carborundum paper and finally polished with a commercial silver cleaner. Because the polyester resin was clear, the cut surface of the otolith could be examined with light incident at various angles. The most satisfactory result was obtained in this way from heated otoliths viewed with reflected light incident at about 45° to the cut and polished surface. Though many very good specimens were produced, the method was too time consuming for use on a large number of samples.

The technique of polishing the cut surface, then etching it with dilute acid, and either examining it with a mineralogical surface microscope or staining it with a protein stain was also tried, but with little success owing to the appearance of multiple rings which could not be related to any annual pattern.

A quick and satisfactory method was to break the otoliths longitudinally (along the sulcus), then to break the dorsal half (Fig. 2) transversely and heat the broken ends in a very low, incandescent bunsen flame. The extent of heating was critical. The broken tip of the otolith was held in the edge of the flame until it turned dark brown. The otolith was not heated until the surface was burnt to ash as described by some authors.

The heated surface was immersed in cedarwood oil and examined under reflected light with a binocular microscope. A series of narrow dark rings between wider light zones was then visible. The narrow dark rings coincided with the hyaline zones and the wider light zones with the opaque zones in unheated otoliths. The pattern of dark rings and light zones was observed best in the area of the broken otolith adjacent to the longitudinal sulcus, that is, along the lateral radius of the otolith (section X-X in Fig. 3). The rings tended to split and become confused or diffuse along the dorsal radius, but the spacing remained uniform and the rings continuous along the lateral radius. However, in some specimens dark rings were well developed along the dorsal radius, and in many the overall ring pattern made visible over the whole broken end of the otolith was used to age the specimen, especially those in readability category 4 (see below). By comparison McEachran and Davis (1970) found the

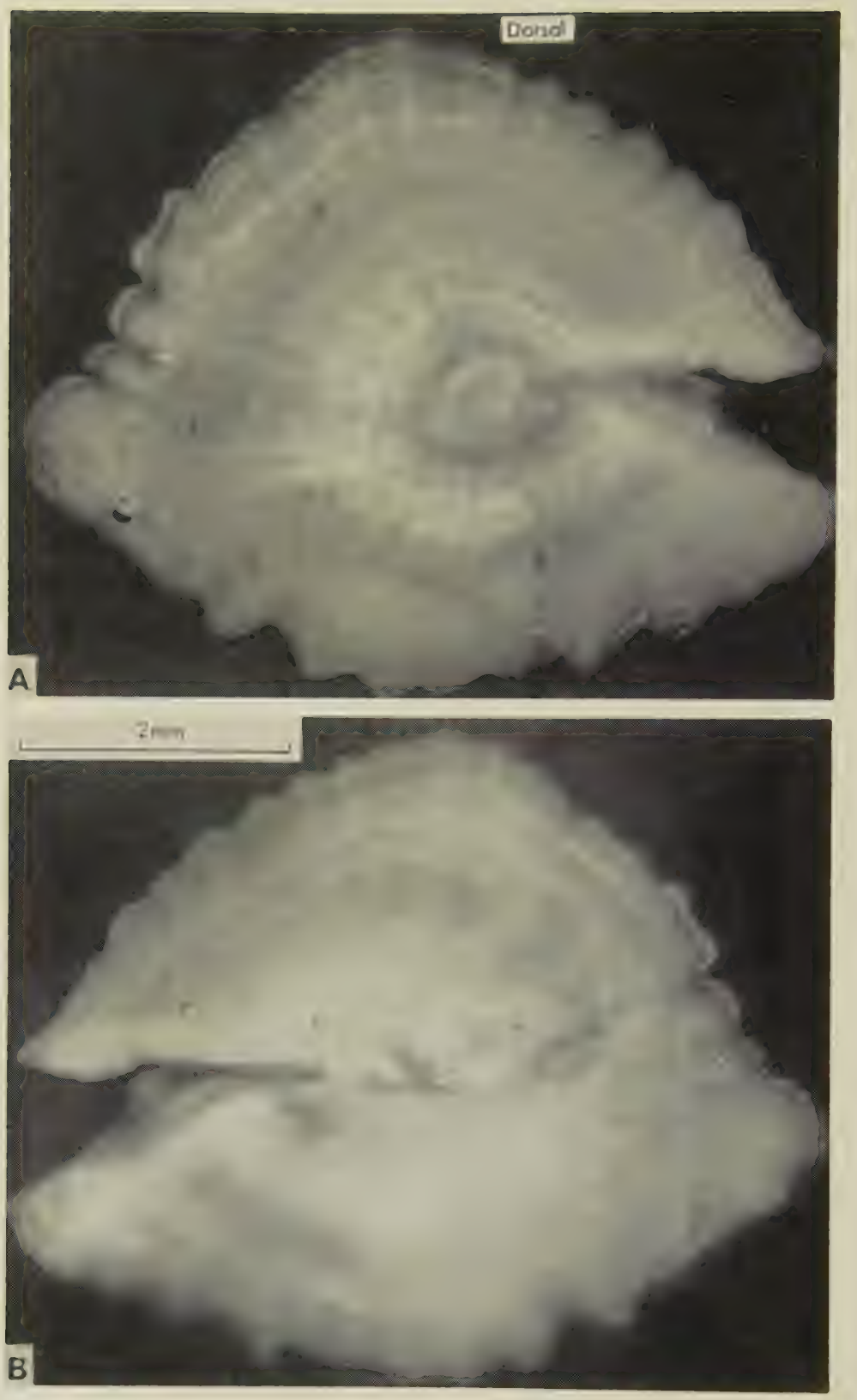


Fig. 2: A whole, unheated otolith from a 4-year-old female red gurnard 43 cm in fork length and caught in Cradock Channel during August. The otolith is from the same fish as the one shown in Fig. 5A. A: Medial surface. B: Lateral surface.

rings well separated along the dorsal radius in the related Atlantic *Prionotus evolans.*

As with *P. evolans,* reorientation of growth on the dorsal margin was observed in some of the older specimens of *Chelidonichthys kumu,* where there was greater deposition of material medial to the dorsal radius. Even in these specimens the ring formation appeared to continue in its uniform pattern along the lateral radius, the rings becoming crowded only as they turned across the dorso-lateral margin of the otolith. It was at this point, where the rings turned on to the dorsal surface of the otolith, that many split or became diffuse. Hence, the only truly reliable axis for reading the dark rings was deemed to be along the lateral radius.

Figure 2 shows a whole otolith of red gurnard photographed with a Carl Zeiss Tessovar photomacrographic zoom system. Figures 3, 4, and 5 show prepared otoliths from fish of various ages photographed with the same equipment.

Figure 3 illustrates how some dark rings, even along the lateral radius, may have a double structure. These double rings have been interpreted as one check.

During examination all otoliths were allocated a readability value from a five-point scale. The allocations were purely subjective.

Readability scale was:

1. **Very easy to read.** Excellent contrast between dark rings and light zones.
2. **Easy to read.** Good contrast between dark rings and light zones, but not quite as marked as in 1.
3. **Readable.** Very little contrast, but rings still apparent.
4. **Readable with difficulty.** Poor contrast; variation in incidence of light source was needed to make rings visible.
5. **Unreadable.**

Results of readability allocations are presented (Table 1). As shown by the table, the greatest percentage of otoliths in category 1 came from the off-

TABLE 1: Percentage of otoliths in each readability category and the total number of otoliths read for each sampling area.

Area	Readability value 1 (%)	2 (%)	3 (%)	4 (%)	5 (%)	Total No. read
Firth of Thames	20	13	31	30	6	1096
Colville	21	17	35	23	4	1303
Cradock Channel	25	21	33	17	4	1001
Te Anaputa	30	21	30	18	1	762

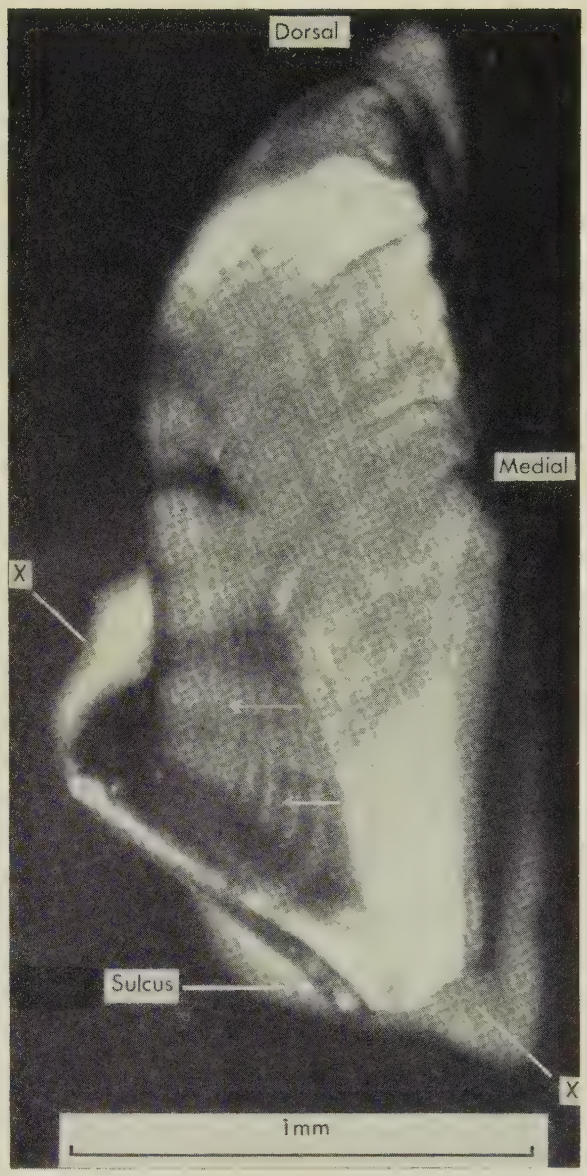


Fig. 3: An otolith broken and heated as described in the text. The otolith is from a 9-year-old female red gurnard 35 cm in fork length and caught in Cradock Channel during February. The double structure of the third and sixth dark rings (arrowed) does not occur in the other rings (see text). The line X-X shows the area where age is read.

shore sampling areas—Cradock Channel and Te Anaputa—which may suggest that seasonal environmental changes are more distinct there than in the more sheltered waters of the inner Hauraki Gulf. In all areas more than 60% of otoliths were in categories 1, 2, or 3, the actual figures being: Firth of Thames 64%, Colville 73%, Cradock Channel 79%, and Te Anaputa 81%. Less than 7% of otoliths in any area fell into category 5, and there was only 1% of this category in the Te Anaputa sampling area.

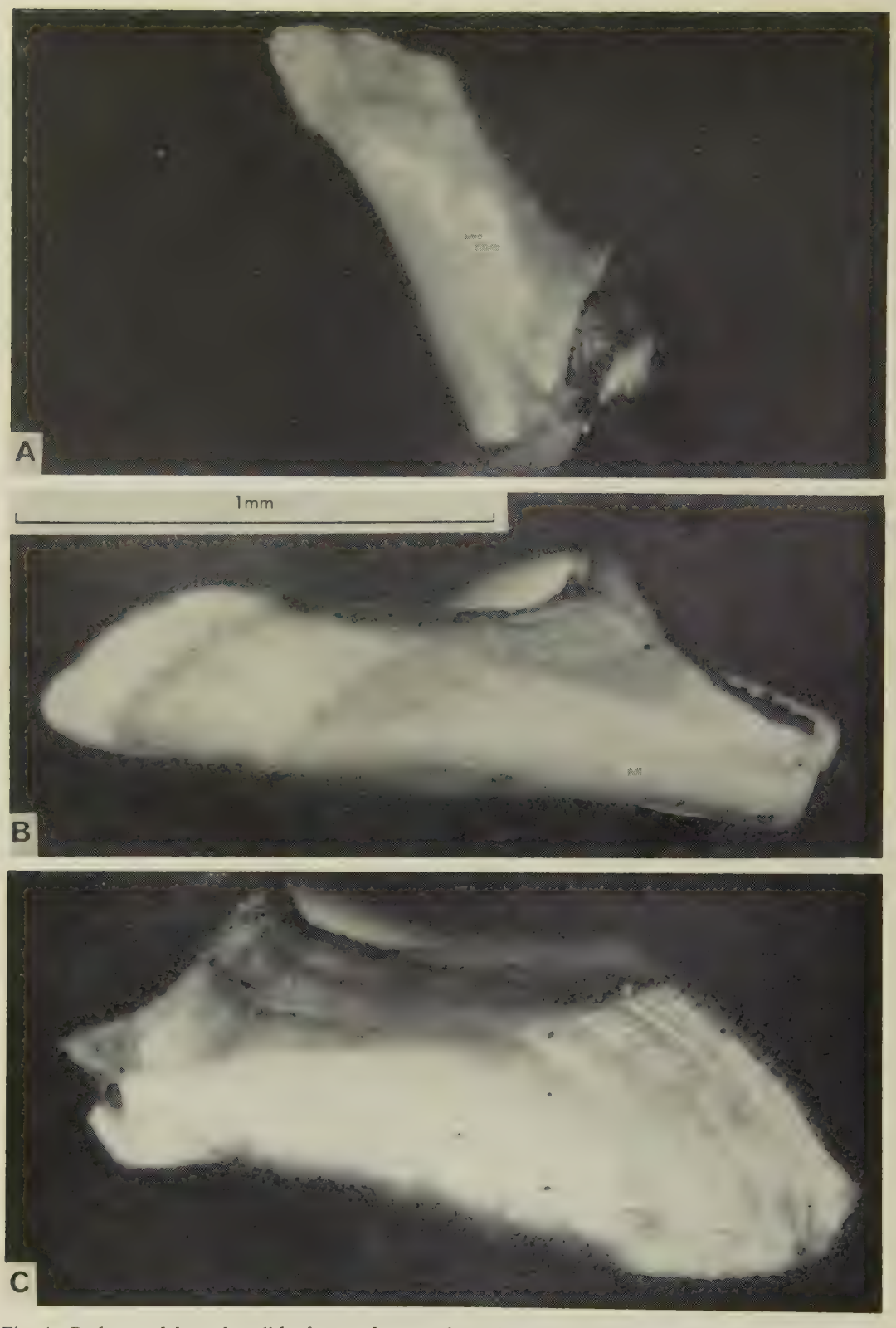


Fig. 4: Broken and heated otoliths from red gurnard caught in Cradock Channel. A: From a 1-year-old male 20 cm in fork length and caught in June. B: From a 2-year-old female 31 cm in fork length and caught in March. C: From a 2-year-old male 26 cm in fork length and caught in August. The outer dark ring is close to the edge in B and well in from the edge in A and C. Annual rings are laid down during December in most specimens. The scale is the same for all three otoliths.

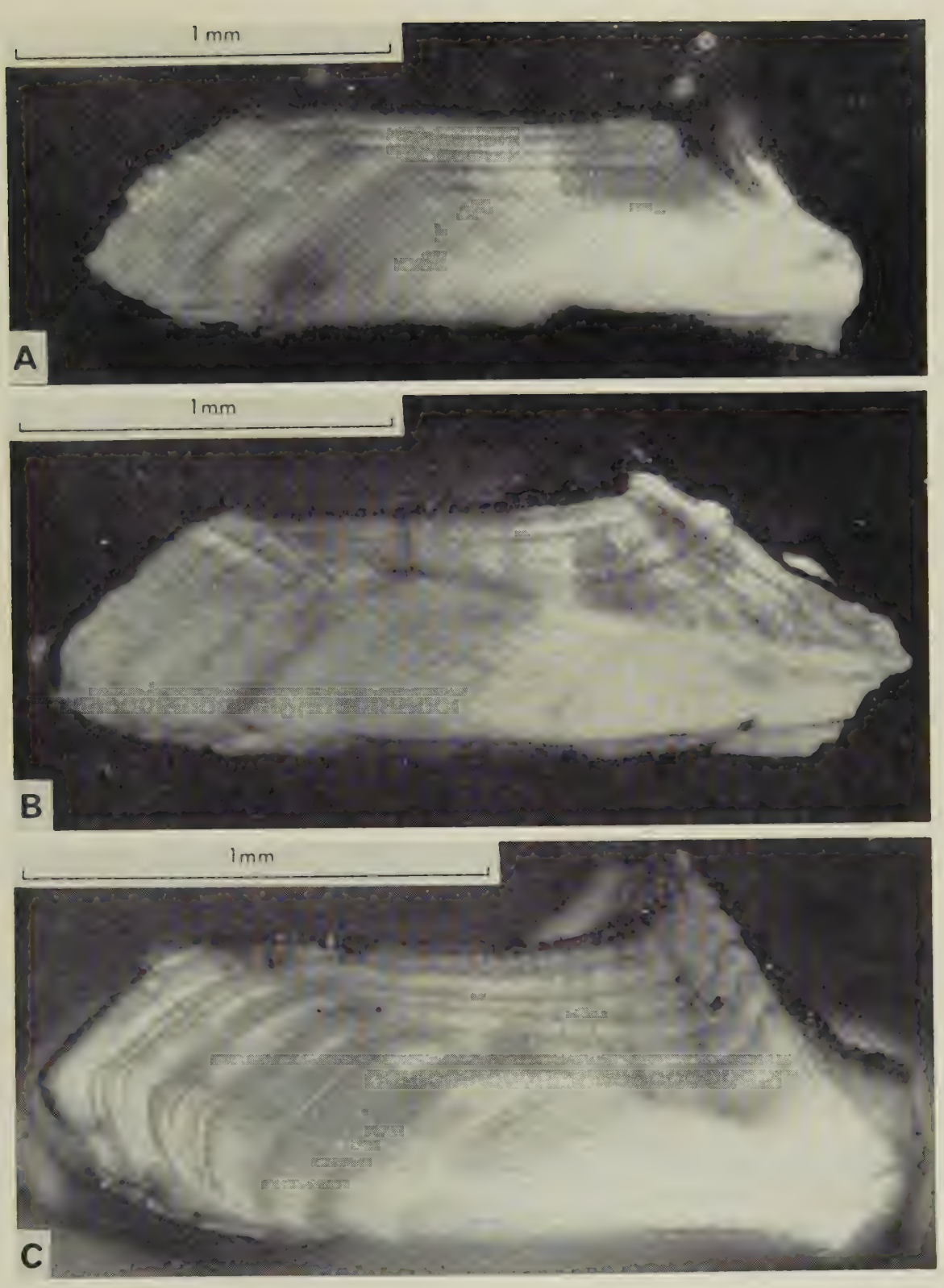


Fig. 5: Broken and heated otoliths from red gurnard caught in Cradock Channel. A: From a 4-year-old female 43 cm in fork length and caught during August. B: From a 5-year-old female 43 cm in fork length and caught during March. C: From a 7-year-old female 34 cm in fork length and caught during December. The outer dark ring is well in from the edge in A, close to the edge in B, and almost on the edge in C. Annual rings are laid down during December in most specimens.

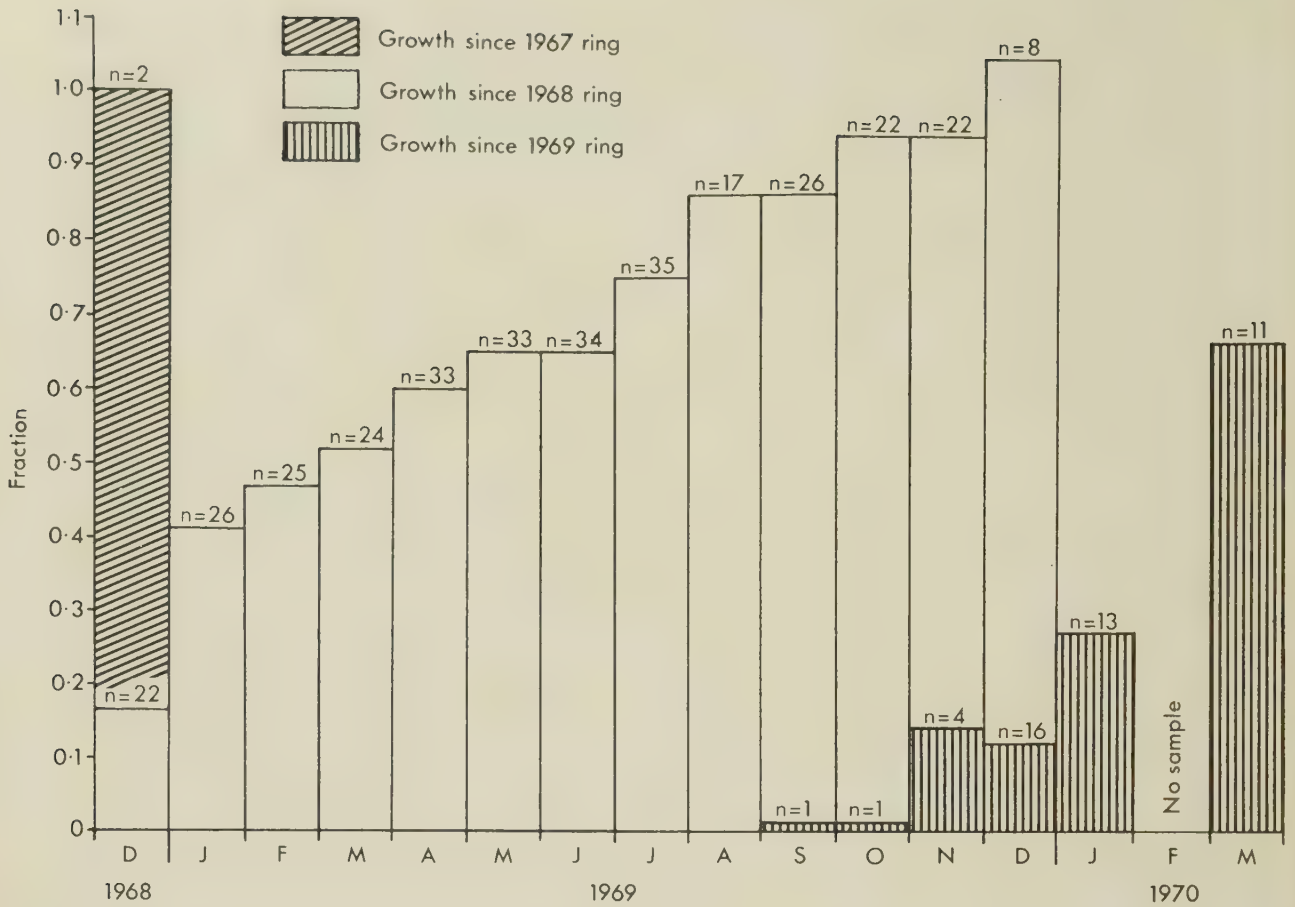


Fig. 6: Proportion of outer light zone width to inner light zone width as a decimal fraction. (Otoliths from specimens taken in the Colville area.)

VALIDATION OF AGEING TECHNIQUE

Otoliths taken from specimens caught each month were examined, after preparation as described above, and the position of the outer dark ring relative to both the edge of the otolith and the dark ring inside it was noted. In this way the width of the light-coloured growth zone laid down since the formation of the last dark ring could be compared with the width of the light zone between the two outermost dark rings. The outer light zone was narrow compared with the inner light zone in otoliths from fish caught in January and February and wide in otoliths from fish taken in August, September, and October. Those otoliths taken from fish caught in December showed much variation in outer zone widths, but were either very wide or very narrow, most being narrow. This suggested that usually the dark ring was laid down during late winter or spring and became visible close to the edge of the otolith during December, when light-coloured material was deposited outside it. Those otoliths collected during December which had a wide outer light zone presumably had a dark ring on the edge, but this was not apparent because no light-coloured material had been deposited outside it to provide the contrast.

To quantify the above findings otoliths with a readability value of 1 or 2 from the Colville and Cradock Channel sampling areas were used to make measurements, in eyepiece micrometer units, of the widths of the outer light zone and the previous light zone. The proportion of the outer zone width to the inner was then calculated as a decimal fraction. The mean values of the fractions for each month are shown in Figs. 6 and 7 to illustrate the gradual increase in the width of the outer light zone as the year progresses. The highest values for these decimal fractions were obtained from December samples. Samples from September to December included not only high values but some very low ones. When they occurred together the number of specimens with high values exceeded those with low values until December.

In combination the cessation of high values and the onset of low values are judged to be sufficient evidence to confirm the hypothesis that the dark

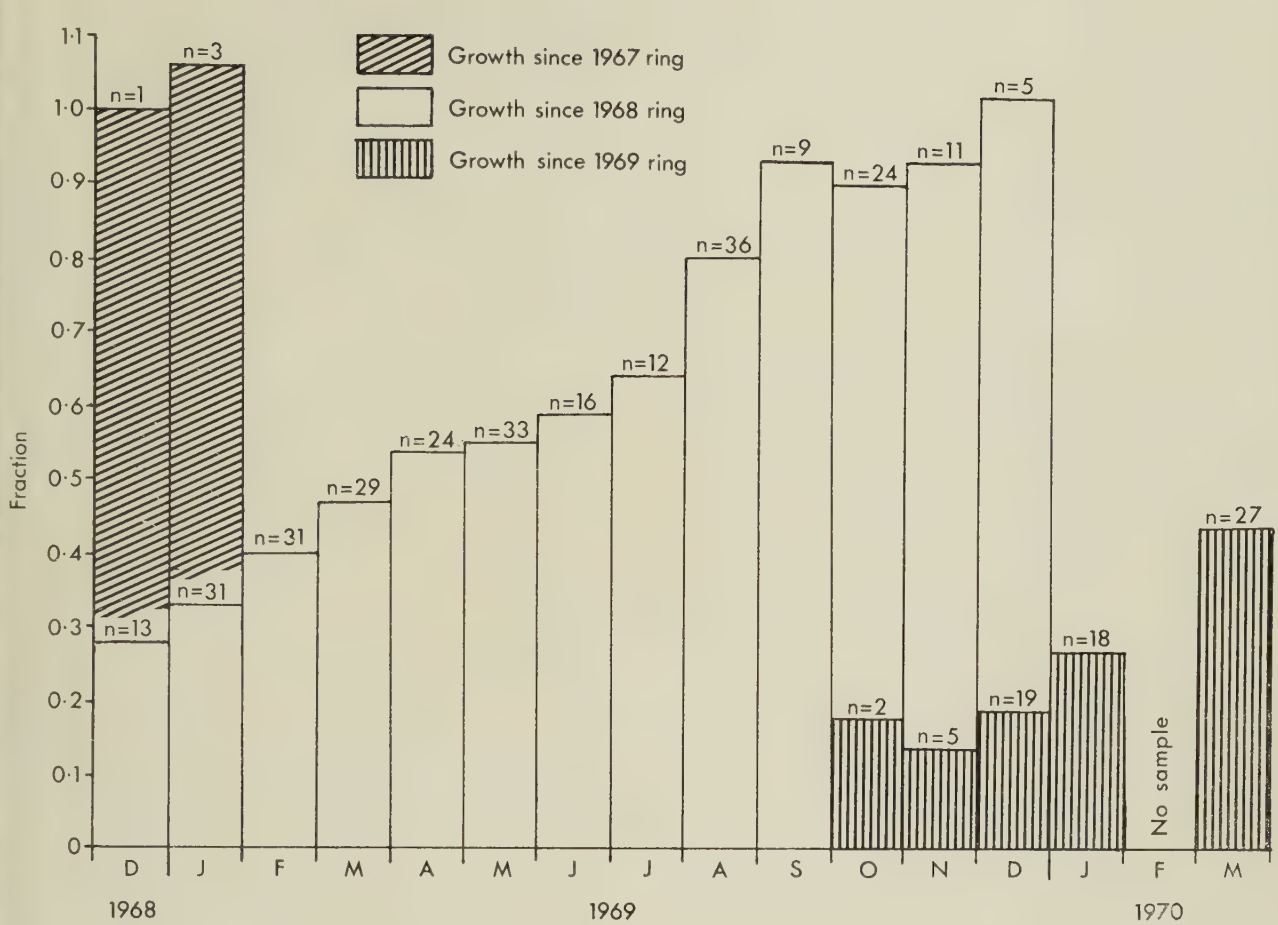


Fig. 7: Proportion of outer light zone width to inner light zone width as a decimal fraction. (Otoliths from specimens taken in the Cradock Channel area.)

rings are deposited annually and in most specimens become visible in December. For this reason, and because it was about the middle of the spawning season (see the section "Reproduction"), a "birthday" of 1 December was chosen as the datum for all age information on red gurnard in this study.

AGE AND GROWTH

INTRODUCTION

The most common asymptotic growth model is the von Bertalanffy growth equation, commonly written:

$$l_t = L_\infty \ (1 - e^{-K(t-t_0)}) \quad . . \quad . . \quad (1)$$

where l_t is length of an individual at age t, L_∞ is the theoretical maximum attainable length, and K and t_0 are constants, the latter being the age at which growth following this law theoretically begins.

If growth is to be examined in terms of weight, equation 1 becomes:

$$w_t = W_\infty \ (1 - e^{-K(t-t_0)})^3 \quad . . \quad . . \quad (2)$$

where w_t is the weight of an individual at age t; W_∞ is the theoretical maximum attainable weight, and K and t_0 are constants as above.

Where the weight of a fish is proportional to the nth power of its length, the exponent 3 in equation 2 is replaced by the exponent n.

In the following section age and growth are considered in terms of length only.

THE VON BERTALANFFY GROWTH EQUATION

The von Bertalanffy growth equation is usually fitted to age-length data on fish by a Ford-Walford plot, also called a Walford line (Ford 1933, Walford 1946, Beverton and Holt 1957, Ricker 1958, Gulland 1969), but this method has the disadvantage of requiring data at equal intervals of time. Thus data on age and length from individual fish must be averaged to provide mean lengths for each age group. Equal weight is then placed on the length information for each age group, despite a possibly poor representation of the young and old age groups in the sample, which may cause a considerable bias in their mean lengths. Much information is therefore lost.

Allen (1966) explained a least squares method for estimating the parameters L_∞, K, and t_0 which has particular value because it places no limitations on the spacing of observations and gives equal weight to the age-length data from each specimen. This technique has been used in this study. Allen also described the method for obtaining the error of estimate of the parameters which may be used with Student's t values to determine fiducial limits.

A computer was used to make the calculations. The iteration facilities provided by the computer enabled calculation of a very accurate final estimate of K (in this case $\pm$ 0.000 01); hence it became unnecessary to apply the correction factor when calculating the value of t_0 as described by Allen.

The birthday of 1 December was used to calculate the actual age of individual specimens as follows: Specimens taken after 1 December were given an age equal to the number of rings counted on their otoliths plus the fraction of the year that had elapsed since that date until their capture. Thus a fish with two rings on its otolith that had been caught on 7 January was given the age:

$$2 + \frac{37}{365} = 2.10 \text{ years}$$

Sexes were kept separate during fitting as were data from the different sampling areas. Data from the whole sampling period, December 1968 to March 1970, were included in the calculations.

Results

Values for the constants in the von Bertalanffy growth equation were determined for each sampling area and sex and are presented with the total numbers of fish of each sex caught in the sampling areas (Table 2). Growth curves corresponding to the growth equations for each area and sex are shown (Fig. 8). The curves have not been continued below age group 1+, because few fish of the 0+ age group were caught.

As described by Allen (1966), the 95% confidence limits for the constants are determined from the formula:

$$\text{constant} \pm t_{N-3} \times \text{S.E. (constant)}$$

The 95% confidence limits are presented in Table 3.

Figure 8 and Tables 2 and 3 show, for all areas, that males have a slower growth rate and lower L_∞ than females from the same area. The highest value for a male L_∞, that for the Firth of Thames, only just exceeds the values for the Cradock Channel and

Te Anaputa females. However, it should be noted that only 154 male fish were caught in the Firth of Thames during the sampling period, compared with 444 for the next lowest total sample size for an area (Te Anaputa males).

The Cradock Channel males show the slowest post-2-year-old growth rate and also have the lowest L_∞ value of the eight growth curves. I believe that this fact is closely linked with the spawning behaviour of the species in the Hauraki Gulf, which will be discussed later.

The growth curves in Fig. 8 also indicate that the rate of growth for post-2-year-old fish, both male and female, is considerably higher in the Firth of Thames than in the Colville, Cradock Channel, and Te Anaputa areas. Further, there is a similarity between the growth curves for the latter three areas, this similarity being exhibited to a less extent by the male growth curves.

Because of these similarities and because trawl and Danish seine fishing are excluded from the Firth of Thames (these methods accounting for most of the gurnard landings (New Zealand Marine Department 1956-71)) it was thought appropriate to combine the data on age and length from the Colville, Cradock Channel, and Te Anaputa areas to provide combined growth curves for each sex which would be appropriate for the analyses in later sections of this bulletin.

The curves calculated for the combined areas are shown (Fig. 9), the Firth of Thames growth curves being included for comparison. The equations for these growth curves are:

Female

$$l_t = 36.4\ (1 - e^{-0.641(t-0.189)})\ \text{cm}$$

Male

$$l_t = 28.8\ (1 - e^{-0.569(t+0.552)})\ \text{cm}$$

As would be expected, the growth rate and L_∞ for the combined male data are less than those for the combined female data. The growth curve for Firth of Thames males approximates that for combined females and the curve for Firth of Thames females shows a higher growth rate and L_∞ than that for combined females.

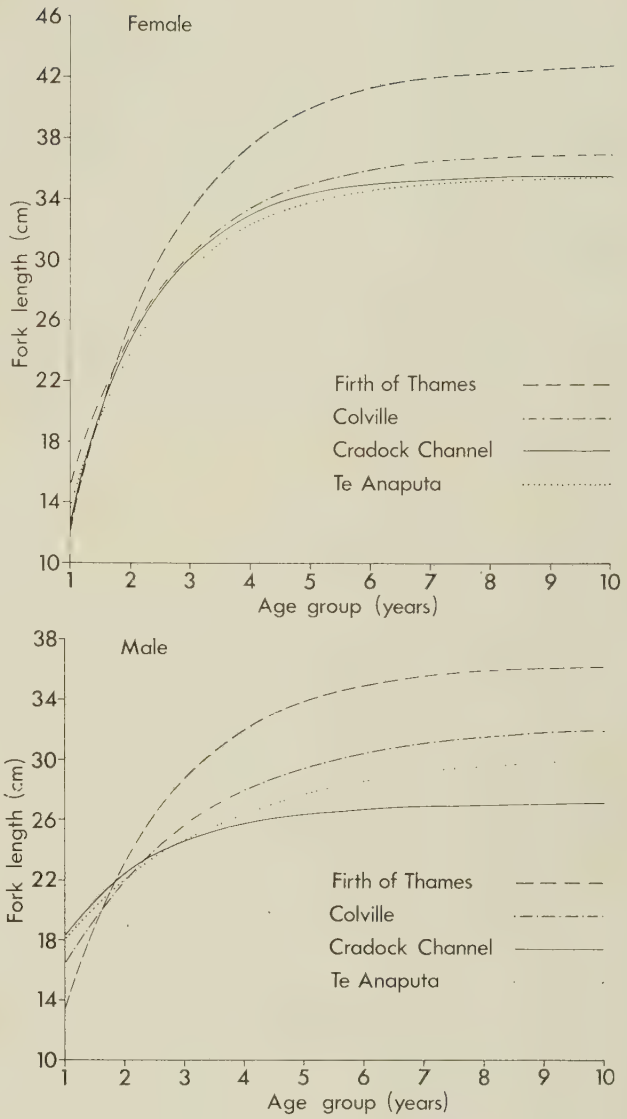


Fig. 8: Von Bertalanffy growth curves for red gurnard from different sampling areas in the Hauraki Gulf (sexes separate).

TABLE 2: Calculated values and their standard errors for the constants in the von Bertalanffy growth equations for each area.

Area	Sex	No.	L_∞	S.E. L_∞	t_0	S.E. t_0	K	S.E. K
Firth of Thames	F	1782	43.1	0.26	0.429	0.0289	0.585	0.0146
	M	154	36.4	1.78	0.166	0.158	0.551	0.0947
Colville	F	2666	37.2	0.25	0.123	0.0424	0.597	0.0195
	M	746	32.3	0.54	−0.644	0.140	0.434	0.0352
Cradock Channel	F	642	35.7	0.41	0.414	0.141	0.729	0.0649
	M	1169	27.1	0.22	−0.768	0.268	0.630	0.0651
Te Anaputa	F	517	35.7	0.36	0.246	0.126	0.631	0.0469
	M	444	30.5	0.60	−1.375	0.386	0.374	0.0520

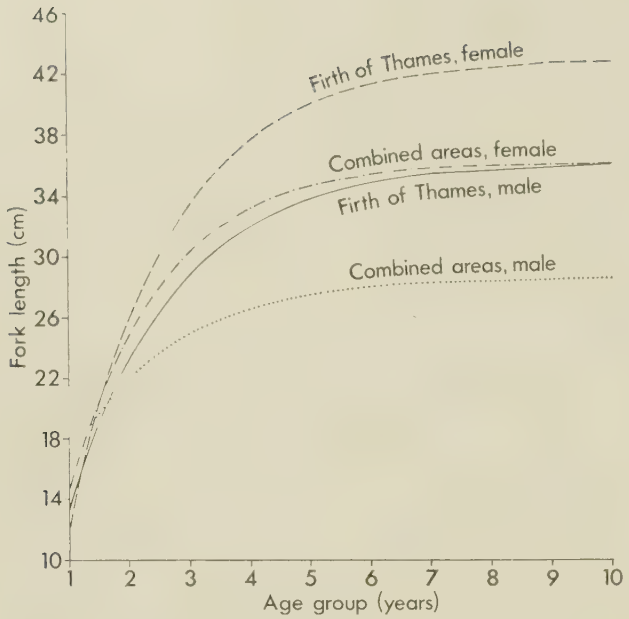


Fig. 9: Von Bertalanffy growth curves for the combined Hauraki Gulf areas and for the Firth of Thames.

COMPARISON WITH PREVIOUS WORK ON THE SPECIES

Staples (1967) studied age and growth of the red gurnard with six samples from Pegasus Bay, east coast of the South Island, taken over a 7-month period during summer and autumn. He found no differences between the growth of males and females. This conclusion was based on a comparison of mean lengths at each age for a sample of 106 females and 32 males from five age groups; two of the male age groups were represented by only one fish each.

Staples determined values for the constants in the von Bertalanffy growth equation by a Walford plot, using values of mean fork length for each age. The mean fork length values were determined by a back calculation technique applied to otolith annual ring

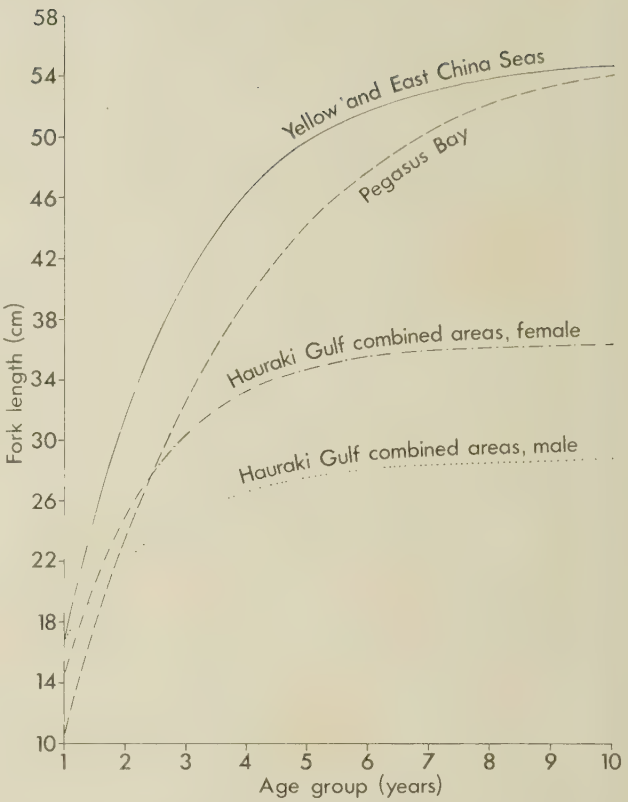


Fig. 10: Von Bertalanffy growth curves for red gurnard from Pegasus Bay (Staples 1967), Yellow and East China Seas (Yunokawa 1961), and Hauraki Gulf combined areas.

radii measurements. The von Bertalanffy growth equation so calculated was:

$$l_t = 57.04\ (1 - e^{-0.319(t - 0.336)})\ \text{cm}$$

These values, of L_∞, K, and t_0, may be compared with those I found. The growth curve for Pegasus Bay red gurnard is shown in Fig. 10 with the Hauraki Gulf combined areas male and female growth curves.

Comparison of the present results with those of Staples makes it apparent that red gurnard from Pegasus Bay have a higher growth rate and larger

TABLE 3: 95% confidence limits for the constants in the von Bertalanffy growth equations for each area.

Area	Sex	L_∞	t_0	K
Firth of Thames	F	42.6, 43.6	0.372, 0.486	0.557, 0.614
	M	32.9, 39.9	−0.146, 0.478	0.364, 0.739
Colville	F	36.7, 37.7	0.372, 0.486	0.557, 0.614
	M	31.2, 33.3	−0.919, −0.369	0.366, 0.503
Cradock Channel	F	34.9, 36.5	0.138, 0.691	0.602, 0.856
	M	26.7, 27.5	−1.294, −0.242	0.503, 0.758
Te Anaputa	F	35.0, 36.4	0.001, 0.493	0.539, 0.723
	M	29.3, 31.7	−2.136, 0.614	0.271, 0.476

L_∞ than those from the Hauraki Gulf. This raises the question of how real is the magnitude of the difference between the two areas. I consider that the magnitude may be overestimated owing to the restricted sampling in Staples's study. However, comparison of the length-frequency distribution of Staples's samples with that of samples from the Hauraki Gulf shows that a greater number of large fish, that is, over 40 cm in fork length, are taken in Pegasus Bay, which indicates either that the fish are growing faster or are surviving to an older age. Staples's age analysis lends support to the first alternative.

The same species, *Chelidonichthys kumu*, also occurs in the East China and Yellow Seas. Yunokawa (1961), studying age and growth of coastal populations in those areas, calculated values for the parameters in the von Bertalanffy growth equation as follows:

$$l_t = 54.82\ (1 - e^{-0.494(t-0.256)})\ \text{cm}$$

The curve corresponding to this equation is also shown in Fig. 10. The curve compares more closely with that calculated by Staples for Pegasus Bay red gurnard than it does for the Hauraki Gulf population. Up to age 2 years the growth rate of the Japanese fish is apparently more rapid than that of the Pegasus Bay fish. However, Yunokawa gives no information on the numbers of specimens in each age group in his samples, nor any information on length frequency or possible sexual differences.

Fisheries literature contains many statements that fish of the same species tend to be smaller in warmer waters than in cooler waters, but that they tend initially to grow faster in warmer waters. Beverton and Holt (1959, page 167) note: "Differences in environmental temperature . . . affect both K and L_∞ ; thus with an increase in water temperature K increases roughly proportionally with the logarithm of temperature and L_∞ decreases, but to a lesser extent . . ."

The differences in growth rate and L_∞ between the Pegasus Bay and Hauraki Gulf red gurnard may therefore simply be a result of temperature differences associated with the difference in latitude (7°) between the two areas. However, the growth differences are large; so other factors may be involved, such as competition—both intraspecific and interspecific.

The Hauraki Gulf red gurnard may be underexploited because of the strong preference in the commercial fishery there for snapper (*Chrysophrys auratus*). This preference could mean that intraspecific competition in gurnard is high because of a relatively low fishing mortality. Alternatively, there may be high interspecific competition between gurnard and snapper. Stocks of snapper in the Hauraki Gulf are the largest in New Zealand waters, and this species is caught on mainly the same grounds as red gurnard. Godfriaux (1969, 1970) showed that snapper and red gurnard feed on almost the same food items, with crustaceans, especially Brachyura, being the most important group in the food of both species. By comparison snapper are relatively uncommon in waters south of Cook Strait and no other species occurs with an equivalent abundance to provide the same level of interspecific competition with the red gurnard. Therefore the competition for food offered by the snapper is suggested as an important factor in the reduced growth rate and L_∞ of the Hauraki Gulf red gurnard population.

POPULATION STRUCTURE

LENGTH-FREQUENCY DISTRIBUTIONS IN THE SAMPLES

Length-frequency polygons for each sex in each of the monthly samples are shown (Figs. 11A-D).

The different length-frequency distributions of males and females are immediately obvious, the males mostly being distributed at the lower end of the length range. Generally the largest fish came from the Firth of Thames, and they were female. Also

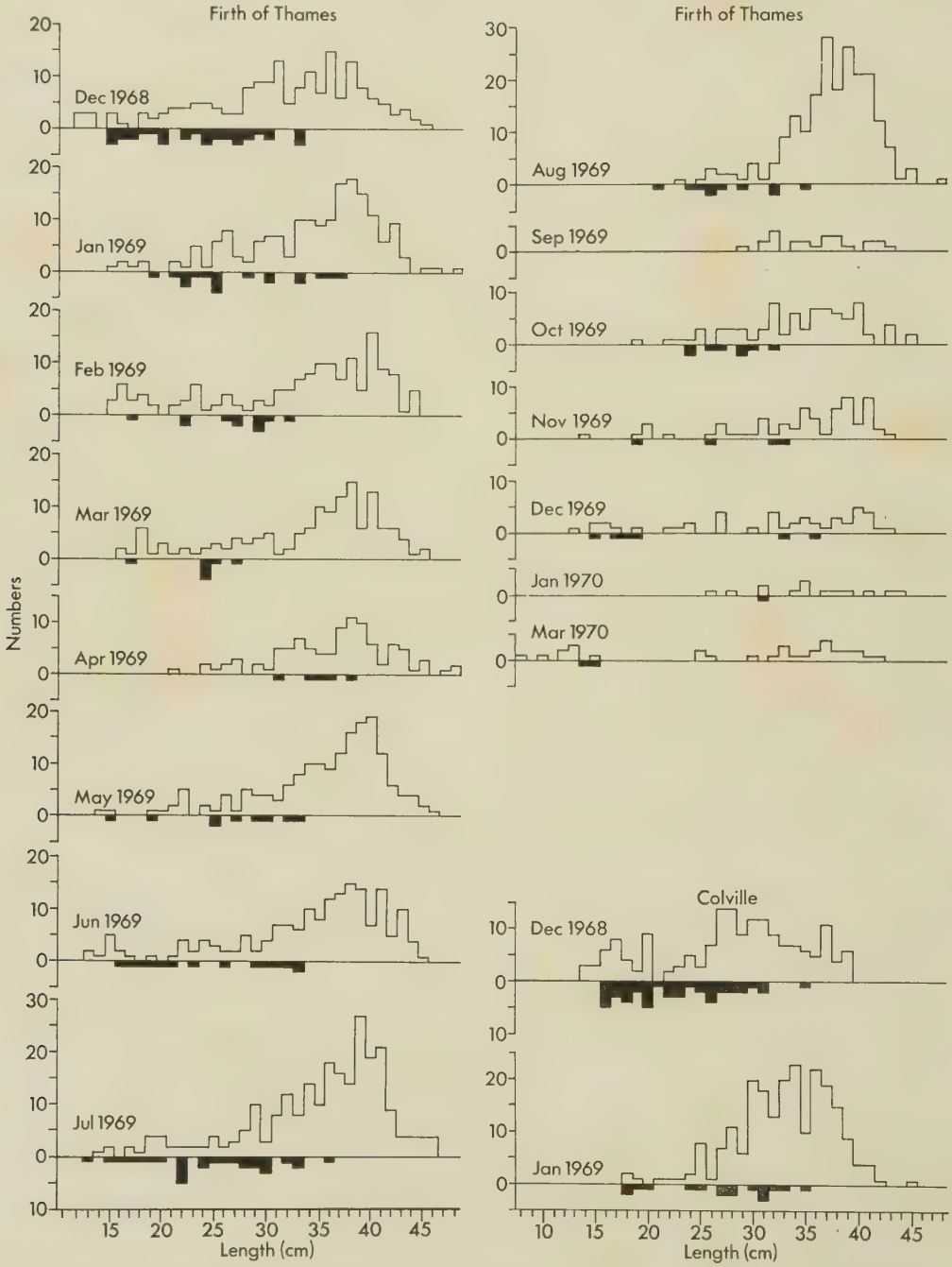


Fig. 11A: Length-frequency distributions by sex for each of the monthly samples from the Firth of Thames and for monthly samples for December 1968 and January 1969 from Colville. Those for females are shown in white and those for males in black.

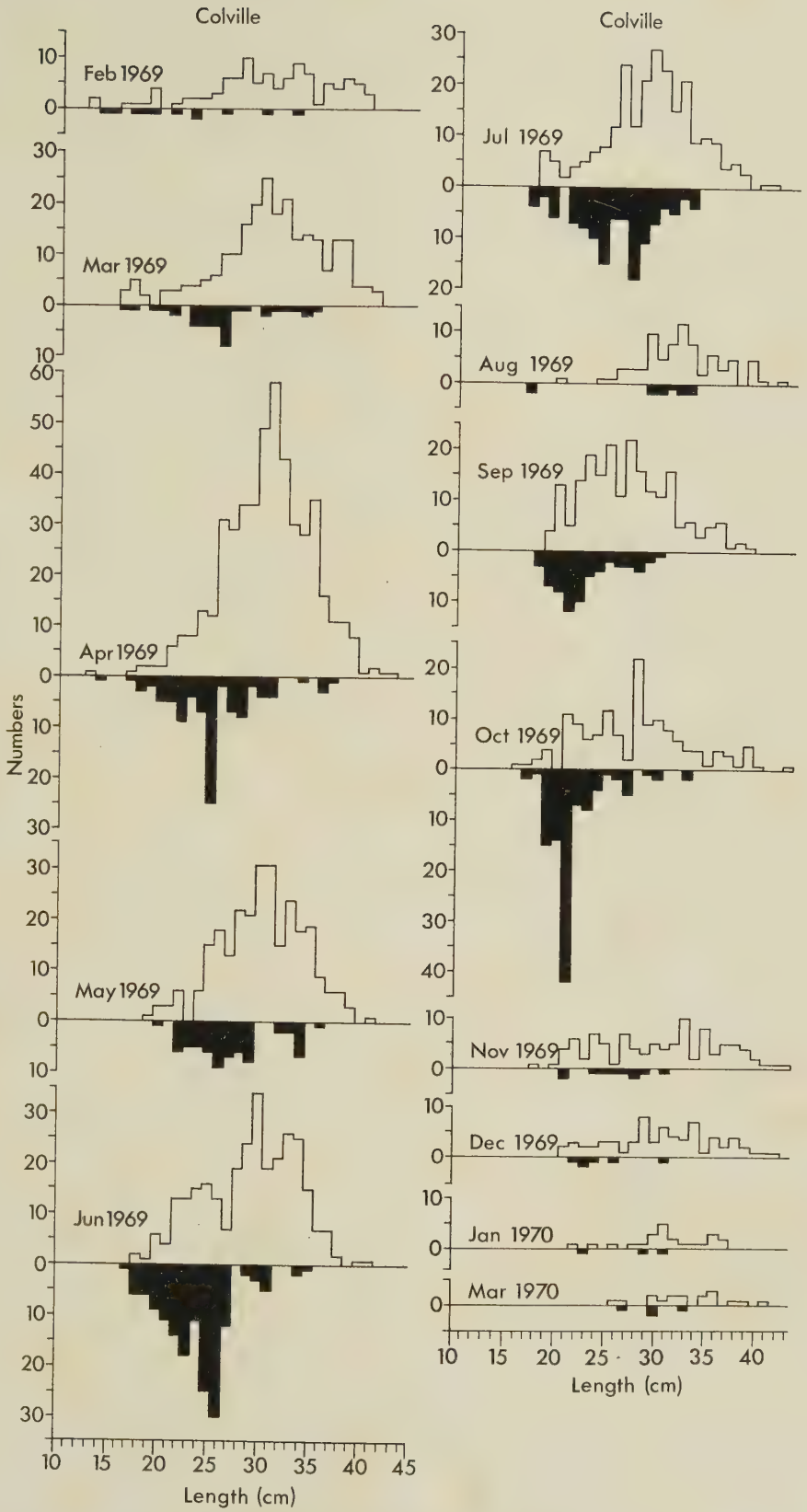


Fig. 11B: Length-frequency distributions by sex for each of the monthly samples from Colville from February 1969 to March 1970. Those for females are shown in white and those for males in black.

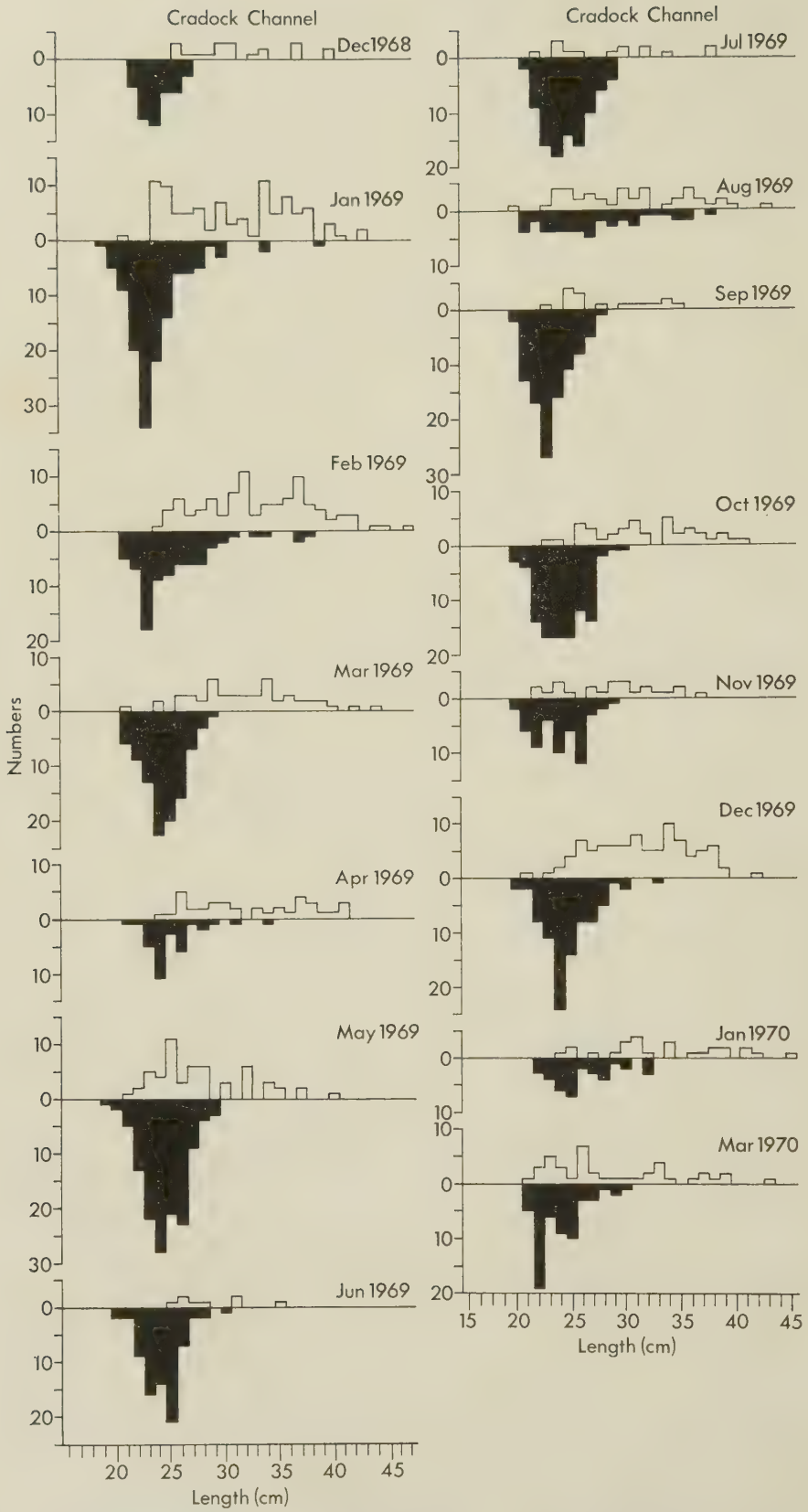


Fig. 11C: Length-frequency distributions by sex for each of the monthly samples from Cradock Channel. Those for females are shown in white and those for males in black.

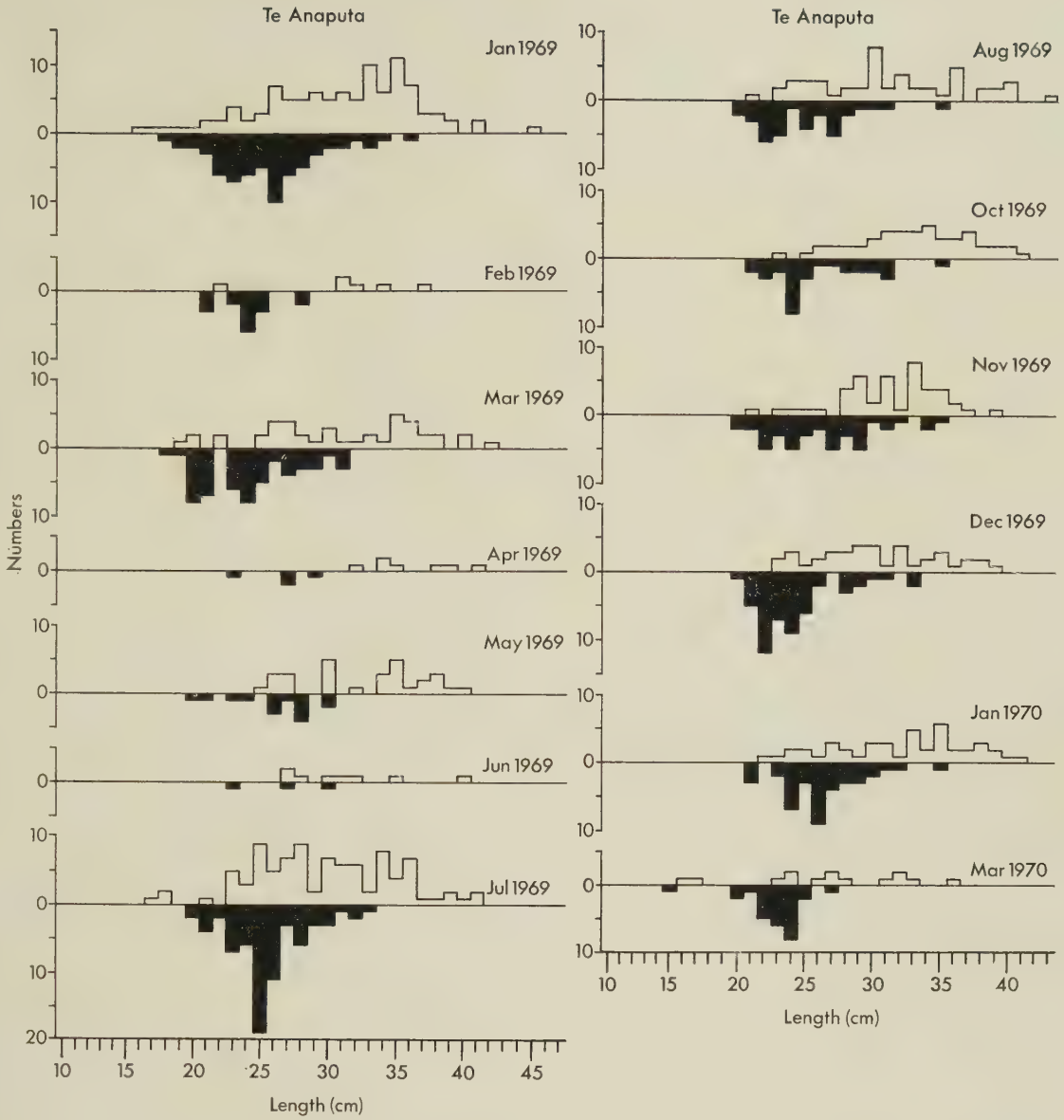


Fig. 11D: Length-frequency distributions by sex for each of the monthly samples from Te Anaputa. Those for females are shown in white and those for males in black.

immediately obvious are the varying sex ratios with geographic area—males being only a small proportion of the total catches in the Firth of Thames, a larger proportion in the Colville area, and generally dominant in Cradock Channel. The sexes were about even in the Te Anaputa area. Thus sex ratios changed with depth, the proportion of males increasing with increase in depth. (The subject of sex ratios and the implications of change in sex ratio with time of year are discussed further in the section "Reproduction".)

Figures 11A-D also show that the length-frequency method of separating age groups was unsatisfactory for the present data.

AGE STRUCTURE

Figures 12 and 13 show the percentage of occurrence of age groups for each sampling area, and for the unweighted total of all areas combined, for each sex during the 12-month period December 1968 to November 1969. The December to November period was chosen for a complete year of sampling data because 1 December had been taken as the birthday of red gurnard in the Hauraki Gulf (see the section "Otoliths and Age Determination") and hence all fish of a given age group belonged to the same year class for the whole of the period.

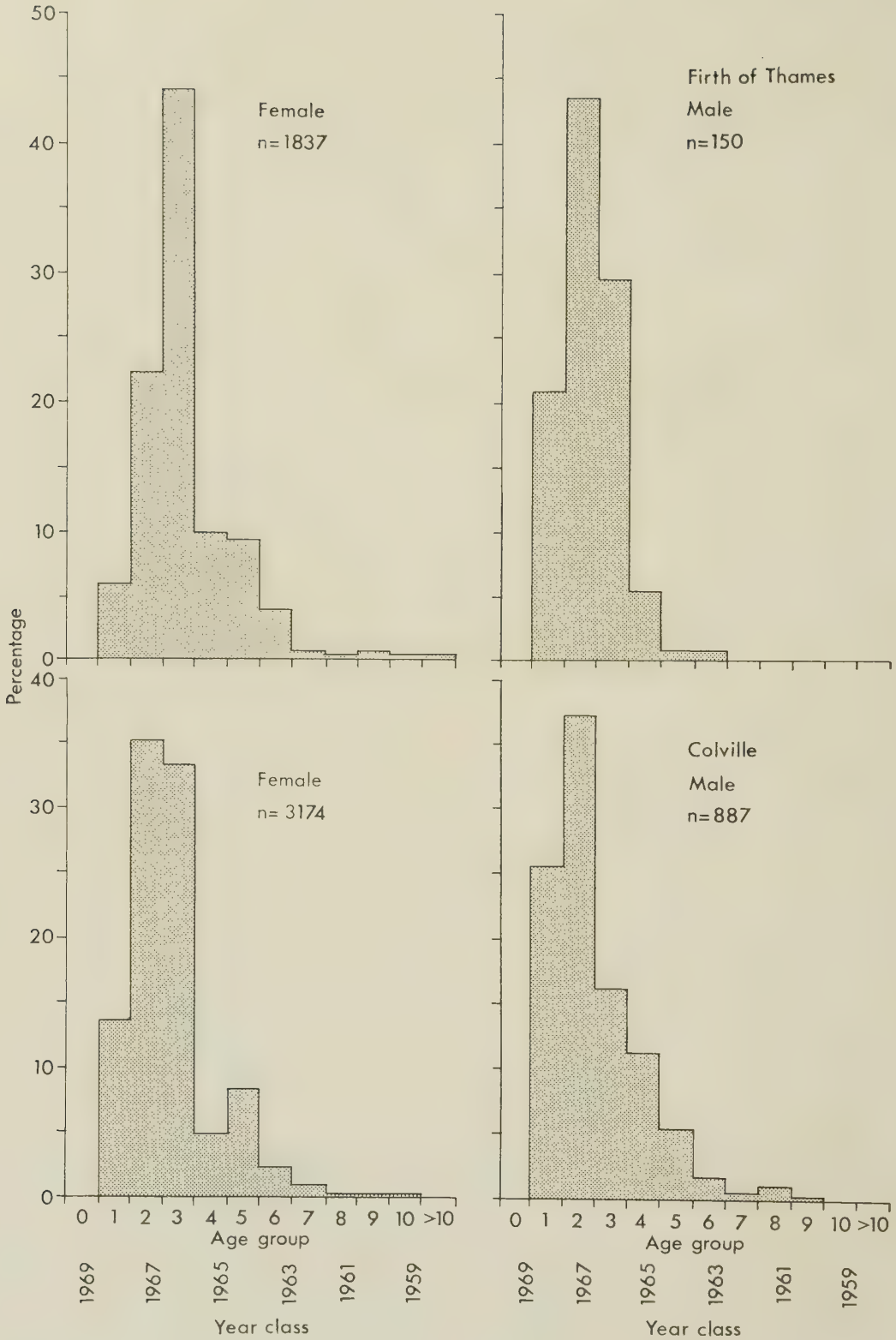


Fig. 12 (above and right): Percentage of occurrence of age groups for the 12-month period December 1968 to November 1969.

Female
n=490
Cradock Channel
Male
n=988
Female
n=421
Te Anaputa
Male
n=326
Percentage
0 10 20 30 40 50 60
0 1 2 3 4 5 6 7 8 9 10 >10
Age group
1969 1967 1965 1963 1961 1959
Year class

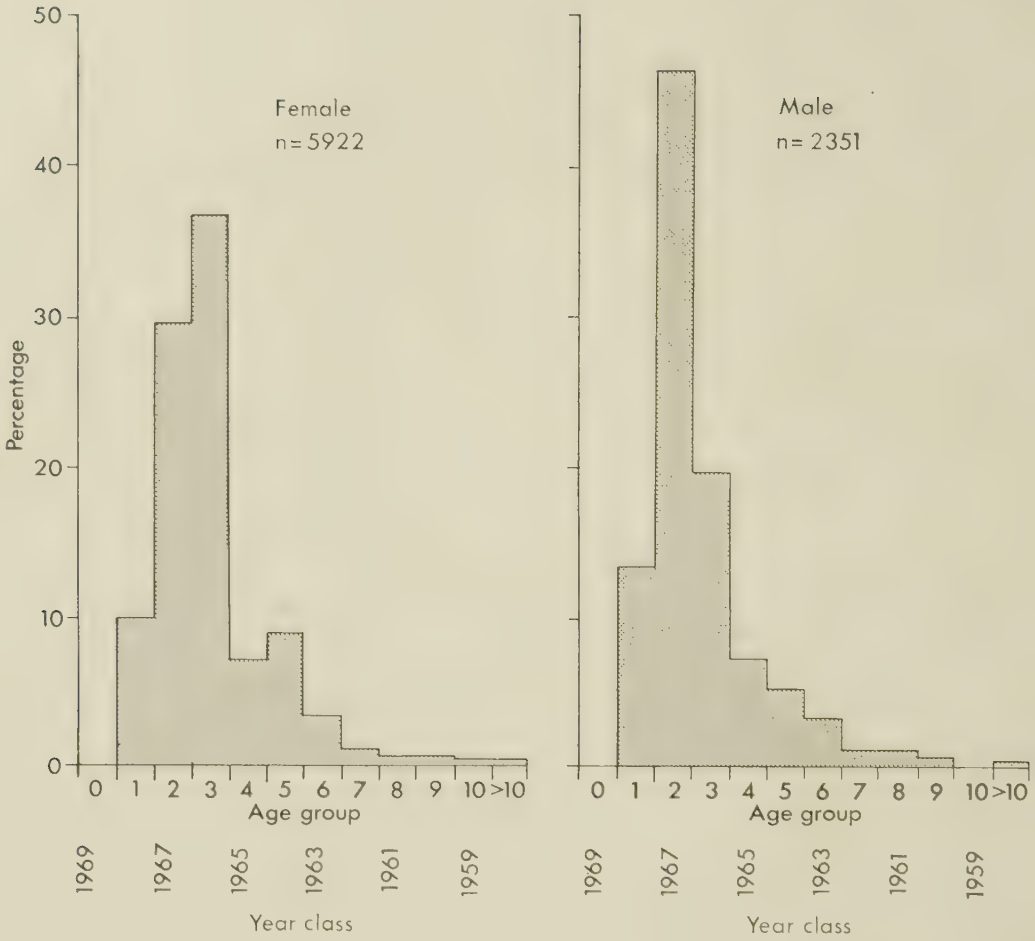


Fig. 13: Percentage of occurrence of age groups, unweighted total of all areas, for the 12-month period December 1968 to November 1969.

Females of age group 3+ were the dominant group in all areas except Colville, where age group 2+ represented a slightly higher percentage (Fig. 12). The dominance of 2-year-old fish in the area may be an indication that it is close to a nursery ground (see the section "Reproduction"). For male fish the dominant age group in all areas was the 2+ age group. Therefore it is reasonable to assume that females are fully recruited on to the trawling and Danish seining grounds by age 3 years and that the males are fully recruited a year earlier at age 2 years. Further, the occurrence of 1- and 2-year-old females and 1-year-old males (in the Colville area) on the trawling and Danish seining grounds suggests that recruitment is gradual. (The age of recruitment to the fishing grounds is the age at which the fish move from the nursery ground to the fishing ground and is distinct from age at entry to the fishery, which is the age at which they become vulnerable to the fishing gear in use. See the section "Yield per Recruit Isopleth Diagrams".)

Young of the year, the 0+ age group, of both sexes were totally absent from the Cradock Channel and Te Anaputa sampling areas. A small percentage of both males and females of the age group were present in the Colville area, and a small percentage of females were also present in the Firth of Thames, males of the age group being absent from this latter area also.

There is some indication that the 1964 year class, 5-year-olds in 1969, was a dominant year class. It represented a higher percentage of the catch of females than did the 1965 year class in the Colville and Te Anaputa areas and only a slightly lower percentage in the Firth of Thames. Similarly, males of the 1964 year class were more numerous than those of the 1965 year class in the Cradock Channel and Te Anaputa areas.

Males of the 1963 year class, 6-year-olds in 1969, were in turn slightly more abundant than males of the 1964 year class in Cradock Channel, and 6-year-old females were about equally abundant to 4-year-old females in the Te Anaputa area.

These figures suggest that a constant rate of recruitment is unlikely for the species in the Hauraki Gulf.

The percentage distribution of age groups for the unweighted total of all areas combined (Fig. 13) confirms that females are fully recruited on to the trawling grounds at age 3 and males at age 2. The dominance of age group 5, the 1964 year class, is also noted for the females.

Table 4 shows the mean annual catch rate per area, and unweighted mean of all areas combined, of age groups in numbers per hour of trawling for each sampling area and sex during the 12-month period December 1968 to November 1969. The mean annual catch rate of an age group and sex in an area is simply the total number of fish of the age group and sex caught during the 12 months divided by the total number of hours trawled in the area during the period.

The value of the table and figures is in illustrating the relative abundance of age groups between areas within sexes and between sexes within areas.

Distinct differences in catch rates for individual age groups were extremely obvious between areas and sexes, and some anomalies occurred. Whereas the catch rates of 1-, 2-, and 3-year-old females in the Colville area were much greater than those in the Firth of Thames, the catch rate of 4-year-olds in the Colville area was slightly less than that in the Firth of Thames. For age groups 6 and older the catch rates were not greatly different between the areas. Similarly, though 2-year-old males in Cradock Channel outnumbered those in the Colville area, 4-year-old males in the latter area were more abundant than the same age group in Cradock Channel.

TABLE 4: Mean annual catch rate (numbers per hour trawled) of age groups for each area, and the unweighted mean annual catch rate of all areas combined, for each sex during 12-month period December 1968 to November 1969.

Age group	Firth of Thames	Colville	Cradock Channel	Te Anaputa	Unweighted mean annual catch rate, all areas combined
			FEMALE		
0	0.03	0.15	0	0	0.04
1	3.76	16.72	0.05	0.54	4.44
2	13.88	42.70	2.83	2.94	13.20
3	27.16	40.27	4.64	3.57	16.43
4	6.22	5.90	1.45	0.97	3.27
5	5.95	10.29	0.76	1.74	4.06
6	2.55	2.90	0.50	0.94	1.55
7	0.54	1.33	0.33	0.31	0.57
8	0.40	0.19	0.43	0.20	0.32
9	0.50	0.19	0.10	0.43	0.29
10	0.37	0.19	0	0.17	0.17
>10	0.37	0.08	0.12	0.20	0.19
			MALE		
0	0	0.08	0	0	0.02
1	1.04	8.65	0.93	0.60	2.39
2	2.18	12.61	13.60	3.57	8.21
3	1.48	5.52	4.71	2.17	3.48
4	0.27	3.85	0.79	0.83	1.29
5	0.03	1.90	1.02	0.97	0.96
6	0.03	0.61	1.07	0.66	0.64
7	0	0.15	0.52	0.14	0.23
8	0	0.34	0.31	0.23	0.23
9	0	0.08	0.29	0.09	0.13
10	0	0	0.12	0	0.04
>10	0	0	0.17	0.06	0.07
Hours of fishing	29.75	26.25	42.00	35.00	Total 133.00

The variations in mean annual catch rates between areas are probably due to the reproductive behaviour of the species, including spawning migrations and drift of eggs and larvae, which are discussed in the section "Reproduction".

MORTALITY AND SURVIVAL

INTRODUCTION

The mortality of individual year classes between years could not be studied directly because data on the relative abundance of year classes during at least 2 successive years were not available. Therefore the relative age composition of the catch in 1 year has been used in catch curves (Ricker 1958) to make estimates of total mortality. Catch curves are plots of log frequency, or log relative abundance, against age group.

It is assumed that the population of red gurnard is continuous over the whole range of the sampling areas and that the catch per unit effort figures represent local abundance (see the section "Reproduction").

Because of the distinct difference in catch rates between areas (Table 4) I have used a *weighted* mean annual catch rate (numbers per hour trawled) of each age group as the measure of relative abundance in the present calculations.

Data were weighted as follows (see Table 5 for details): The catch rate of individuals of all age groups was summed for each area and sex. These figures were then divided by the total number of hours fished in each area during the 12-month period to provide the mean annual catch per hour (numbers) of individuals of all age groups for each area and sex. Separate weighting factors for males and females in each area were then calculated by taking the lowest mean annual catch rate for each sex and dividing the value into the other mean annual catch rate figures for the same sex. The lowest mean annual catch rate then had a weighting factor of 1 and the other catch rates had weighting factors equal to the quotients. This provided the eight weighting factors (four for each sex) shown in Table 5.

In addition to the weighting factors themselves Table 5 shows that the mean annual catch rates of females (all age groups combined) in the Cradock Channel and Te Anaputa areas were almost equal and only one-tenth of that in the Colville area. The mean annual catch rate of females in the Firth of Thames was, in turn, half of the Colville rate.

The lowest mean annual catch rate of males (all age groups combined) was in the Firth of Thames, the figure being almost half of the Te Anaputa rate, which was in turn less than half of the Cradock Channel mean annual catch rate. The Cradock Channel figure was two-thirds of that for Colville.

The weighting factors were applied in the following manner to provide truly representative average catch rates for each age and sex: with the sexes kept separate, the mean annual catch per hour of each age group in each area was multiplied by the weighting factor for the area and sex and the products were summed over the areas and sexes within each age group. The sums were then divided by the sum of the weighting factors for each sex to provide weighted mean annual catch per hour figures for each age group of each sex. In mathematical notation this may be represented by:

$$CR_{ij} = \frac{\Sigma(P_{ik} \cdot R_{ijk})}{\Sigma P_{ik}}$$

where i is sex, j is the age group, k is the sampling area,

CR is the weighted mean annual catch rate (numbers per hour),

P is the weighting factor,

R is the mean annual catch per hour (numbers).

TABLE 5: Calculation of weighting factors for the 12 months' age-frequency data, December 1968 to November 1969.

Area	Total No. of fish of all ages caught	Total trawling time (h)	Mean annual catch rate (total No. all ages/h trawled)	Weighting factor
		FEMALE		
Firth of Thames	1837	29.75	61.75	5.29
Colville	3174	26.25	120.91	10.36
Cradock Channel	490	42.00	11.67	1.00
Te Anaputa	421	35.00	12.03	1.03
		MALE		
Firth of Thames	150	29.75	5.04	1.00
Colville	887	26.25	33.79	6.70
Cradock Channel	988	42.00	23.52	4.67
Te Anaputa	326	35.00	9.31	1.85

$$\text{Weighting factor} = \frac{\text{larger catch/h}}{\text{least catch/h}} \text{ (per sex)}$$

The results of these calculations are presented in Table 6 in the column headed *N*.

These results may be compared with the unweighted mean annual catch per hour figures for all areas combined in Table 4. The changes, apart from the increased catch rate of individuals of all age groups combined, are not great, but are still very important to the estimation of total mortality. The main changes caused by weighting have been to increase further the catch rate of 1-year-old females over that of 4- and 5-year-old females and to raise the catch rate of 1-year-old males to the same level as that of 3-year-old males.

The log relative abundance of each age group used in the catch curves is also presented in Table 6.

MORTALITY AND SURVIVAL RATES

Separate catch curves for males and females are shown (Fig. 14). The important points in the calculation of mortality are those of the descending right limit of the catch curve—age 3 to older than 10 for females and age 2 to older than 10 for males—and further discussion is limited to these data.

The points are well scattered, especially for females, which reflects probable variation in recruitment. The points were tested for curvilinearity with orthogonal polynomials (Bruning and Kintz 1968, Sokal and Rohlf 1969) and the quadratic term was found to be not significant in both sexes.

Straight line regressions were then fitted to the data on each sex, the slope of the line being equal to $-\hat{Z}$ (where $\hat{Z}$ is the estimate of the total instantaneous mortality coefficient). Standard errors ($S_{\hat{z}}$) and 95% confidence limits for the regression coefficients, the sample estimates of $-Z$, were calculated.

Female

$Y = 4.83 - 0.65X \qquad S_{\hat{z}} = 0.074$

$\hat{Z} = 0.65$

95% confidence limits for Z: $0.48 \leqslant Z \leqslant 0.83$

Male

$Y = 3.33 - 0.60X \qquad S_{\hat{z}} = 0.037$

$\hat{Z} = 0.60$

95% confidence limits for Z: $0.52 \leqslant Z \leqslant 0.69$

TABLE 6: Mean annual catch rate (numbers per hour trawled) for each area and sex and the weighted mean annual catch rate per age of all areas combined with the logs of the values and their percentage distribution.

	Mean annual catch rate (No./h)				Relative abundance (weighted mean annual catch rate (No./h))		
Age group	Firth of Thames	Colville	Cradock Channel	Te Anaputa	*N*	%	$\log_e N$
			FEMALE				
0	0.03	0.15	0	0	0.10	0.11	−2.302 585
1	3.76	16.72	0.05	0.54	10.96	12.09	2.394 252
2	13.88	42.70	2.83	2.94	29.51	32.55	3.384 729
3	27.16	40.27	4.64	3.57	32.19	35.50	3.471 656
4	6.22	5.90	1.45	0.97	5.46	6.02	1.697 449
5	5.95	10.29	0.76	1.74	7.95	8.77	2.073 172
6	2.55	2.90	0.50	0.94	2.55	2.81	0.936 093
7	0.54	1.33	0.33	0.31	0.98	1.08	−0.020 203
8	0.40	0.19	0.43	0.20	0.27	0.30	−1.309 333
9	0.50	0.19	0.10	0.43	0.29	0.32	−1.237 874
10	0.37	0.19	0	0.17	0.23	0.25	−1.469 676
>10	0.37	0.08	0.12	0.20	0.18	0.20	−1.714 798
Weighting factor:	5.29	10.36	1.00	1.03			
			MALE				
0	0	0.08	0	0	0.04	0.16	−3.218 876
1	1.04	8.65	0.93	0.60	4.53	17.97	1.510 722
2	2.18	12.61	13.60	3.57	11.03	43.75	2.400 619
3	1.48	5.52	4.71	2.17	4.53	17.97	1.510 722
4	0.27	3.85	0.79	0.83	2.20	8.73	0.788 457
5	0.03	1.90	1.02	0.97	1.36	5.39	0.307 485
6	0.03	0.61	1.07	0.66	0.73	2.90	−0.314 711
7	0	0.15	0.52	0.14	0.26	1.03	−1.347 074
8	0	0.34	0.31	0.23	0.29	1.15	−1.237 874
9	0	0.08	0.29	0.09	0.14	0.55	−1.966 113
10	0	0	0.12	0	0.04	0.16	−3.218 876
>10	0	0	0.17	0.06	0.06	0.24	−2.813 411
Weighting factor:	1.00	6.70	4.67	1.85			

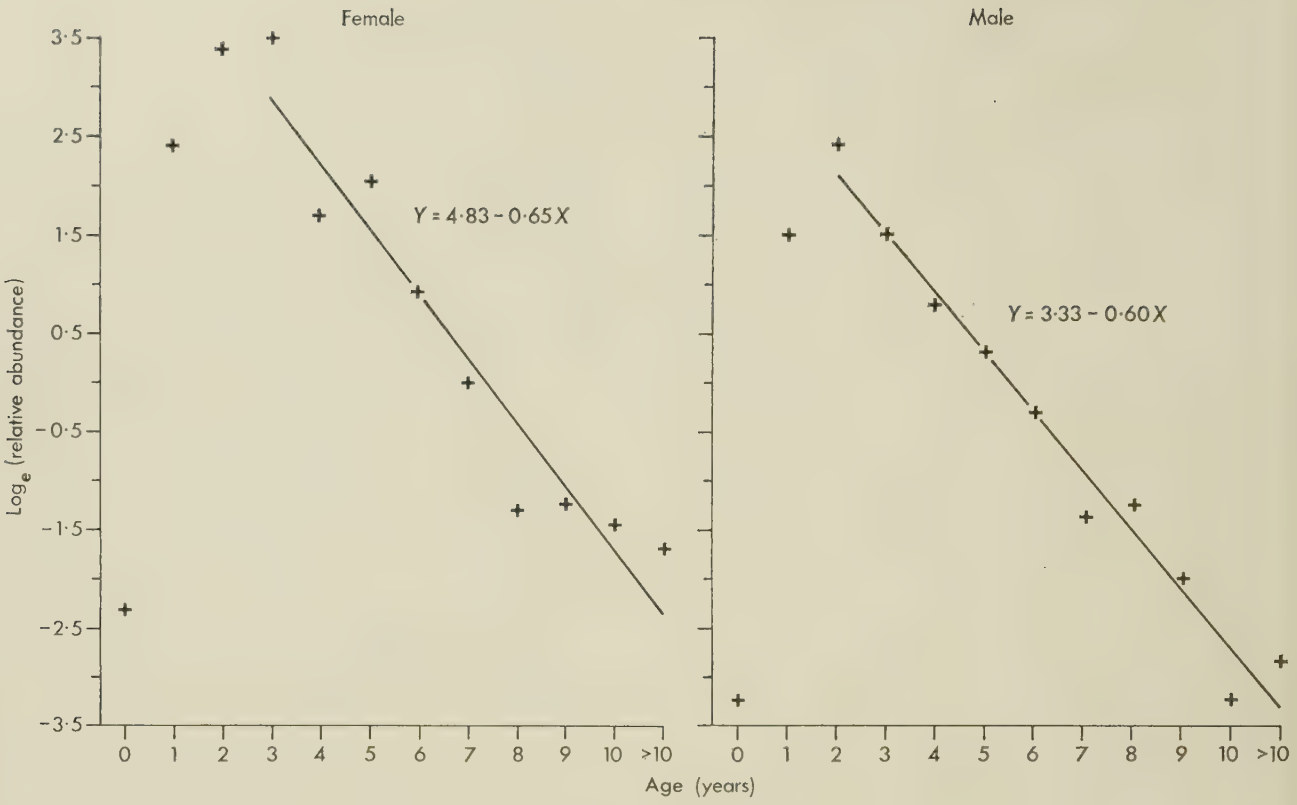


Fig. 14: Catch curves. Relative abundance has been derived as discussed in the text.

The relationship between S, the fraction of an age group surviving from 1 year to the next, and Z is:

$$e^{-z} = S$$

or $$Z = \log_e \frac{1}{S}$$

Therefore, survival rates for each sex are:

$$\text{Female } S = 0.52; \text{ male } S = 0.55$$

Unfortunately, separate estimates of the natural and fishing mortality coefficients could not be determined, as relevant data such as tag returns and change in total mortality associated with change in fishing intensity were not available.

LENGTH-WEIGHT RELATIONSHIPS AND CONDITION

ANALYSIS OF DATA

The literature on length-weight relationships and condition has been well reviewed in other papers, notably that of Le Cren (1951).

The mathematical relationship between length and weight in most fish can be described by a formula of the type:

$$W = aL^b \quad . . \quad . . \quad . . \quad . . \quad . . \quad (3)$$

where W is weight, L is length, and a and b are constants (the value of b usually varying about 3).

For ease of analysis by straight-line regression methods, equation 3 is best converted into its logarithmic form:

$$\log W = \log a + b \,.\, \log L \quad . . \quad . . \quad . . \quad (4)$$

where b represents the slope of the regression line and $\log a$ its elevation on the $\log L$ axis.

Values of b and $\log a$ in equation 4 can be calculated for any set of data by the method of least squares. The expected weight of a fish at a given length can then be determined. However, individual variations from the theoretical weights so calculated are bound to occur and it is these variations in weight for length which are the important considerations in the study of condition.

Where data are available on weight and length for a large number of fish which may be grouped by sex, sampling area, and time of year when caught, as in the present study, the statistical method of analysis of covariance can be employed to make the fullest use of the information available. The analysis of covariance is essentially a statistical comparison of subgroup regression equations and was apparently first applied to fish length-weight data by Le Cren in 1951 (Cassie 1957).

The body weights of gutted fish were used in the present study in an attempt to eliminate the effects of stomach contents and size of gonad (according to its stage of development) on the actual weight of bone and muscle in the fish. I suggest that the condition of a fish in terms of its capacity for survival and reproduction is better measured by weight of muscle and bone alone than by these plus viscera.

The following analyses of covariance between subgroups were made (according to the method of Snedecor and Cochran (1967)) to determine whether a common slope (regression coefficient) could be used for all subgroups as tested:

1. Between sexes, all data combined, to test whether all data on both sexes could be combined under one common regression coefficient.
2. Between areas and months within sexes, to test whether all data on *each* sex could be combined under one common regression coefficient for *each* sex.*
3. Between months† within areas and sexes, to test whether monthly data on each area *and* sex could be combined under one common regression coefficient for each area *and* sex.
4. Between areas and sexes, data for all months combined (within each area and sex).

RESULTS OF THE ANALYSES OF COVARIANCE

The analyses of covariance rejected the hypothesis of common slope for the subgroups as tested in all cases except for data on male fish from the Firth of Thames in analysis 3. These results meant that the estimates of a—adjusted means—could not be used as measures of relative condition.

However, analysis 4 did provide a common regression equation with the least mean square deviation from regression for *all* the length-weight data. The common regression equation for all length-weight data is:

$$\log W = 2.99 \log L - 2.001 \qquad S_{\hat{b}} = 0.0065$$

or $$W = 0.009\,98\, L^{2.99}$$

where $S_{\hat{b}}$ is the estimate of standard deviation of regression coefficient (b), W is weight (g), and L is length (cm). Mean square deviation from regression, $S_{y.x} = 0.001\,75$.

*Only subgroups (monthly samples of one sex) of length-weight where more than 9 observations were available were included in the tests for analyses 2 and 3; all data were used in the other analyses. The number of specimens in each weighed sample is shown in Table 7.

†Between months included testing between the *same* month in *different* years.

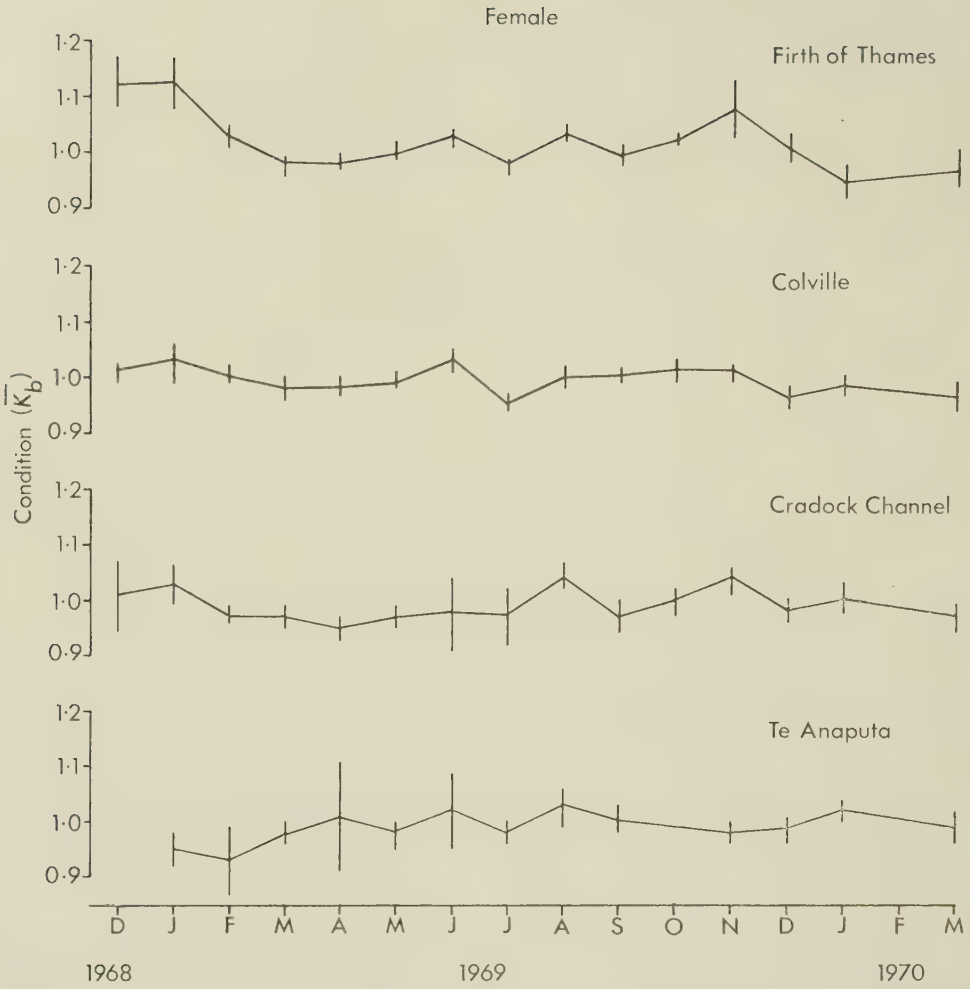
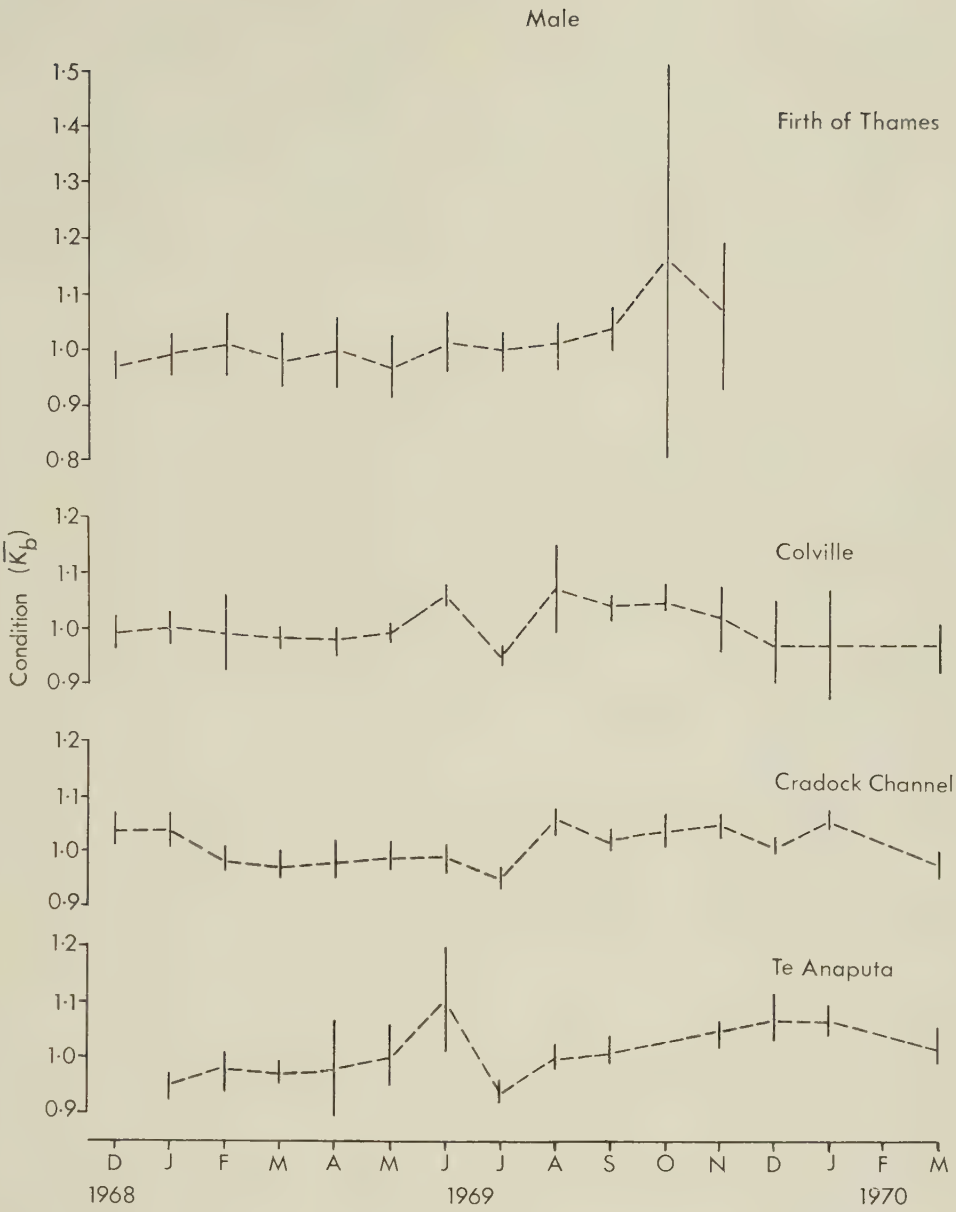


Fig. 15 (above and right): Mean monthly relative condition factor, $\overline{K}_b$, in the four areas, for females and males separately, and the 95% confidence limit of each.

TABLE 7: Number of specimens weighed in each monthly sample.

		Firth of Thames		Colville		Cradock Channel		Te Anaputa	
Year	Month	Female	Male	Female	Male	Female	Male	Female	Male
1968	Dec	120	32	111	43	21	27	No sample	
1969	Jan	101	18	86	15	69	51	83	53
1969	Feb	103	10	86	9	76	52	6	15
1969	Mar	94	12	110	34	44	39	41	44
1969	Apr	80	5	105	48	37	26	7	4
1969	May	99	12	90	46	42	47	26	14
1969	Jun	107	14	89	59	8	34	8	3
1969	Jul	111	26	105	67	14	39	70	46
1969	Aug	78	10	56	11	41	45	47	32
1969	Sep	23	0	88	38	19	39	No sample	
1969	Oct	70	9	92	44	39	40	48	27
1969	Nov	53	4	81	10	25	29	40	36
1969	Dec	44	6	60	6	73	43	39	28
1970	Jan	15	0	24	3	26	31	43	33
1970	Mar	30	0	17	5	38	35	14	22
	Total:	1128	158	1200	438	572	577	472	357



THE VON BERTALANFFY EQUATION FOR RATE OF GROWTH BY WEIGHT

The common length-weight relationship calculated above can be used to convert values of L_∞ in the von Bertalanffy equation for rate of growth in length (equation 1) into values of W_∞ for the von Bertalanffy equation for rate of growth in weight (equation 2).

The growth equations most likely to be typical of red gurnard on the commercial grounds of the Hauraki Gulf are those calculated for each sex from the data for the Colville, Cradock Channel, and Te Anaputa areas combined. Values for the constants in these equations were given in the section "Age and Growth".

The von Bertalanffy equations for rate of growth in weight for the combined areas are therefore:

Female

$$w_t = 469\ (1 - e^{-0.641(t-0.189)})^3 \text{ g}$$

Male

$$w_t = 233\ (1 - e^{-0.569(t+0.552)})^3 \text{ g}$$

The values for W_∞, K, and t_0 in the above equations have been used in the Beverton and Holt yield per recruit model (see "Yield per Recruit Isopleth Diagrams").

RELATIVE CONDITION BY RATIO OF OBSERVED TO EXPECTED WEIGHT

Because adjusted mean weights had been rejected as measures of relative condition by the analyses of covariance, it was decided to calculate relative condition factors, K_b, after Le Cren (1951):

$$K_b = \frac{W}{aL^b} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

$$\text{or} \quad K_b = \frac{W}{\hat{W}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

where a and b are the constants of equations 3 and 4, W is the observed weight, and $\hat{W}$ is the expected weight of a fish of length L.

Although no measure of relative condition can be entirely independent of length (see Cassie 1957), the effects of different length frequencies in the samples can be reduced by using Le Cren's K_b.

The relative condition factor, K_b, has an expectation of 1, which makes higher and lower values of condition easily identified. Values for the constants a and b have already been found: $a = 0.009\,98$, $b = 2.99$, the values for the common regression for all red gurnard length-weight data.

Monthly mean values of K_b ($\overline{K}_b$) and their 95% confidence limits were then calculated for each area and sex. The results are shown in Fig. 15. The confidence limits are based on the sample standard deviation of K_b.

Results

Figure 15 shows that the mean monthly relative condition factors lacked any distinct seasonal trend. There was only a vague pattern of condition being higher during spring and summer and lower during autumn and winter. The points of good and poor condition in each area do not clearly coincide, and the correlation between sexes within each area is not close. The only statement that can be made with some confidence is that before the spawning season, that is, during March, April, and May, the values of $\overline{K}_b$ showed less variation between months than they did during and after the spawning season.

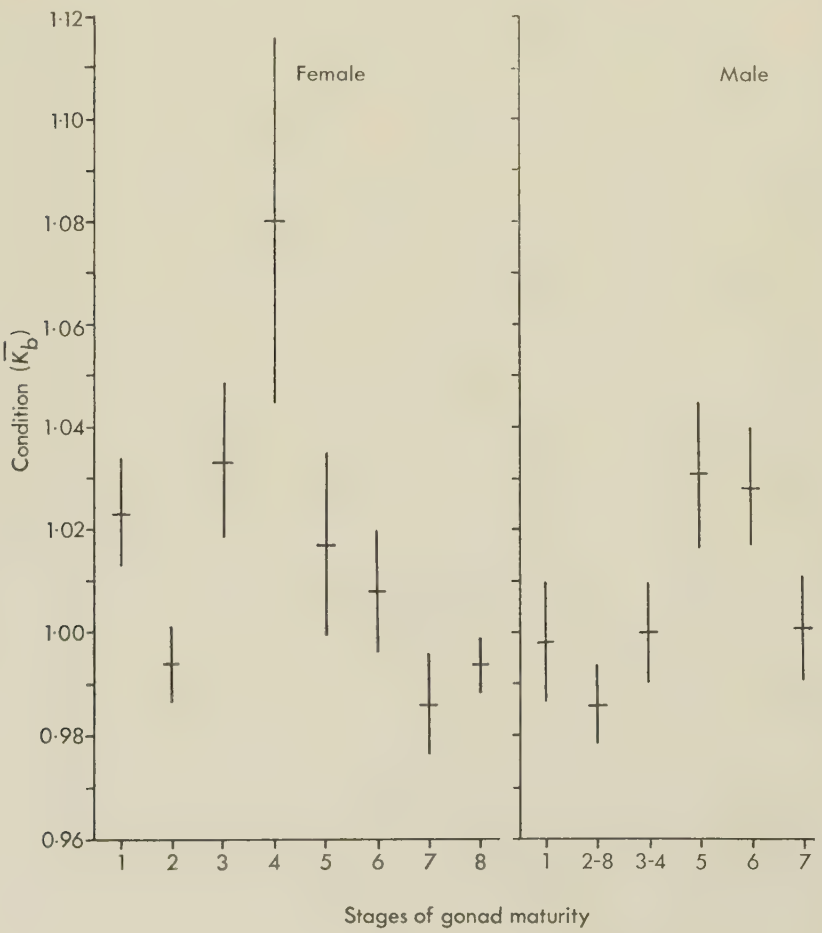


Fig. 16: Mean relative condition factor, $\overline{K}_b$, and 95% confidence interval of $\overline{K}_b$ per gonad stage.

GONAD MATURITY AND CONDITION FACTOR

(The criteria for defining stages of gonad development are described in "Reproduction".)

Analyses of covariance between gonad stages within sexes, data from all areas and months combined, rejected the hypothesis of common slopes for each sex, and therefore adjusted means could not be used as measures of relative condition.

However, the common regression equations for each sex calculated in the analyses of covariance were still the best least squares fit for all the length-weight data on each sex when grouped by gonad stage. The common regression equations are:

Female

$$\log W = 3.03 \log L - 2.048 \qquad S_{\hat{b}} = 0.0102$$

or $$W = 0.008\,95\, L^{3.03}$$

Male

$$\log W = 2.96 \log L - 1.950 \qquad S_{\hat{b}} = 0.0161$$

or $$W = 0.0112\, L^{2.96}$$

The constants a and b (equations 3 and 4) in these common regression equations for male and female data were used to calculate relative condition factors, K_b (equation 5).

The mean values of K_b for each gonad stage of each sex ($\overline{K}_b$) and the 95% confidence limits of the $\overline{K}_b$'s are shown graphically in Fig. 16.

DISCUSSION

During the extended spring-summer spawning season of the red gurnard, as discussed in "Reproduction", many of the catches of sexually mature fish in any one area were composed of fish at various stages of gonad development, from resting through gravid to spent. Thus, though the weight of gonad material had been removed from the length-weight data by gutting to minimise the variations in weight for length with stage of gonad maturity, the effect on actual body weight caused by the gonad cycle was significant.

The magnitude of variation in relative condition with stage of gonad development was found to be less in male fish than in female fish (see Fig. 16). Further, the female fish in best condition were those at stage 4, and the male fish in best condition were at stage 5. The 95% confidence interval of $\overline{K}_b$ for stage 4 females was very large, which indicated a great range of condition among individuals of the stage. It seems reasonable to suggest that the sharp drop from peak condition in females as they became gravid was due to their using food and food reserves for the deposition of yolk in the ova at the expense of building up somatic tissue. The male fish in the meantime were able to continue to increase in condition because the development of spermatozoa placed less demand on their metabolism. Only a slight drop in condition was noted in both sexes as they passed from the gravid to the ripe stage, and this was followed by a more marked decrease in condition as they became spent. In females the lowest mean relative condition factor was shown by spent fish and in males it was found during stages 2-8—maturing virgin, recovering spent, and/or resting.

In summary, the results of calculating the monthly $\overline{K}_b$'s for each area and sex and the $\overline{K}_b$'s for each gonad stage of each sex have shown that condition depends greatly on the stage of gonad development in the annual cycle of gametogenesis. The erratic nature of the variations in relative condition with time of year, when gonad stage was not considered, was probably due to a combination of the effects of both season (and subsequent availability of food) and composition of the samples with regard to the stages of gonad development in the monthly samples.

REPRODUCTION

DETERMINATION OF STAGE OF GONAD MATURITY BY FIELD EXAMINATION

The gonads were readily visible in all but the smallest of specimens when the body cavity was opened by a cut along the mid-ventral line. They lay in a position ventral to the swim bladder and along the grooves formed between the main body of the bladder and its lateral arms.

From each monthly sample the gonads of five fish of each sex in each 1-cm length group were examined macroscopically to determine their stage of maturity. The scale of maturity stages was based on that described in Laevastu (1965). This is an eight-point scale in which size and colour of the gonad as a whole and condition of the contents of the gonad are considered.

Some modifications were made to the original scale to make it more readily applicable to the present species. Size of gonad relative to volume of body cavity was not easily assessed in the red gurnard, and considerable variation was apparent between fish at the same stage of maturity. Therefore, though it was noted, relative volume of gonad was not considered as a vital criterion during staging. Testis stages 3 and 4 of Laevastu's scale were combined into the one stage, 3-4, because of the difficulty in separating them. Similarly, testis stages 2 and 8 were combined into a single stage, 2-8.

Ovaries and testes were easily distinguished in the larger specimens. The ovaries were very flaccid compared with the firm testes, and the pink-red through to orange coloration strongly contrasted with the pinkish white to cream of the testes. The well-developed blood supply was also a most obvious feature of the ovaries. In small virgin specimens, where both ovaries and testes were transparent, the most reliable indication of a male was the angular nature of the testes; in cross section they were almost triangular. Small virgin females were best identified by the already well-developed ovarian blood vessels.

Obviously there was a lower limit to the size at which sexes could be distinguished. In the red gurnard this was about the 13-cm to 15-cm fork length range. However, some specimens taken in this range and below were readily sexed.

Stages of gonad maturity in females are:

Stage 1. Virgin: Ovary very small; transparent, colourless to pink; often found dorsal to lateral arm of swim bladder and close under the vertebral column.

Stage 2. Maturing virgin and/or recovering spent: Ovary translucent; pinkish. Extremely small single eggs may be seen with a magnifying glass.

Stage 3. Developing: Ovary almost totally opaque; red with blood capillaries. Small, irregular, yellow-orange yolk granules apparent to the naked eye.

Stage 4. Developed: Ovary pale orange, but still retaining a reddish tinge. Eggs clearly discernible; opaque. The orange yolk granules have not filled the eggs; so the yolk has an uneven appearance. Ovaries have enlarged to fill about half of the body cavity.

Stage 5. Gravid: Ovaries fill the ventral cavity, many to the extent of bursting out as the cavity is opened. Eggs evenly round, filled with yolk; orange. Close examination reveals eggs of many different sizes, the largest being a little less than 1 mm in diameter (about 0.8 mm).

Stage 6. Ripe or spawning: Ovary contains large, ripe, transparent, colourless eggs scattered randomly among the smaller, orange yolk-filled eggs which characterised stage 5. Ripe eggs measure a little over 1 mm in diameter (about 1.2 mm). Proportion of ripe eggs may vary and when they are abundant the roe runs when slight pressure is applied.

Stage 7. Spent: Ovary, not fully evacuated, has a flaccid appearance and orange to red coloration, greater evacuation leading to more red appearance. Remaining eggs undergoing reabsorption are very uneven in size and irregular in shape.

Stage 8. Resting: Ovary empty, but regaining its good tone and taut appearance; red. A few eggs in the stage of reabsorption may still be visible.

Stages of gonad maturity in males are:

Stage 1. Virgin: Testis very small; transparent, colourless to pink; often found dorsal to lateral arm of swim bladder and close under the vertebral column.

Stage 2-8. Maturing virgin, recovering spent, and/or resting: Testis translucent, creamy white, small, very narrow and angular.

Stage 3-4. Developing and/or developed: Testis becoming swollen; may be slightly lobular. Blood capillaries give an overall pink coloration through the whole length. No milt drops appear when the testis is cut and squeezed.

Stage 5. Gravid: Testis swollen; uniformly milky white in appearance. Milt drops appear when the testis is cut and squeezed.

Stage 6. Ripe or spawning: Testis remains swollen and whitish anteriorly and a rather short length of the posterior part is cream coloured owing to the collection of milt. Milt runs when slight pressure is applied.

Stage 7. Spent: Testis has a dried, somewhat shrivelled appearance. Some milt still remains in the posterior "sac".

To my knowledge there is no published account of any other triglid species which describes all the stages of gonad maturity passed through during the annual cycle of gonad development. However, Marshall (1946) published some information on the appearance of ripe or spawning ovaries in *Prionotus carolinus* and *P. evolans strigatus,* both of which appeared similar.

He wrote (page 124): "The appearance of the ovaries . . . contributes to an understanding of their spawning. Variability of egg size and development is conspicuous throughout [the ovary]. The largest eggs, whether ripe or partially so, are not grouped but are scattered amongst less developed eggs of diverse sizes. Correlated with this is the fact that few eggs are ripe at any one time and the breeding season is somewhat prolonged." This information agrees with the appearance of stage 6 ovaries in *Chelidonichthys kumu,* as noted above.

Fulton (1899), discussing grey gurnard, *Trigla gurnardus,* wrote (page 227): ". . . it is known from the condition of the ovaries and the comparatively small proportion of eggs that become matured at the same time that the period in many cases for all the eggs to be shed is considerable". These published accounts and my observations suggest that partial spawning over a period is common among triglids.

MATURITY INDICES

Body weight and gonad weight were measured separately during sampling (see "Sampling Method"). The gonad weight of male fish was a very small percentage of the body weight at all stages of gonad maturity, being highest for males at maturity stages 5 and 6, when it was about 1% of the body weight. Therefore, except for males at these stages of maturity, the spring balance used to weigh gonads was not sufficiently sensitive to make measures of maturity index for males realistic. Similarly, the gonad weights of virgin females were very small percentages of their body weights, and maturity indices for these fish, also, could not be calculated with any accuracy.

Because of the above limitations, maturity indices were calculated only for sexually mature females and males at gonad stages 5 and 6. Individual maturity indices were calculated from the formula:

$$\text{Maturity index} = \frac{\text{Gonad weight}}{\text{Body weight}} \times 100$$

The following calculations were made:

1. Individual maturity indices.
2. Mean maturity indices per gonad stage and standard deviations of the means per monthly sample.
3. Grand mean maturity indices per gonad stage and standard deviations for the means for all data from the different months combined.

Sexes and sampling areas were kept separate during the calculations.

Because of the long spawning season and migratory behaviour, fish at different stages of gonad maturity were taken together during a number of months (see below). Therefore the mean maturity index of the catch in any area during any month was not a good measure of the pattern of spawning activity in the red gurnard population. However, maturity indices were used to support the reliability of visual determination of the stages of gonad maturity for sexually mature females and mature males at gonad stages 5 and 6. Fish of the one sex at the same stage of gonad maturity, from different months, within sampling areas were combined to provide the information in Table 8.

Table 8 shows that mean maturity indices for females increase gradually during stages 2 to 5, reaching a maximum for ripe (stage 6) fish, then drop sharply as the fish become spent. The greatest range of maturity indices occurred among ripe fish and is probably the result of partial spawning. The fact that few ripe eggs occurred in the ovaries at any one time further supports the suggestion that red gurnard are partial spawners. The large range of maturity indices recorded for ripe females may therefore be caused by already partially spent fish being classified as ripe.

TABLE 8: Mean maturity indices, standard deviations of means, 95% confidence limits of means, and numbers in samples by sex, area, and gonad stage.

Area	Stage of maturity	Mean maturity index	Standard deviation from mean maturity index	95% confidence limits for mean maturity index		No.
			FEMALE			
Firth of Thames	2	0.86	0.23	0.83,	0.89	245
	3	1.16	0.31	1.10,	1.22	117
	4	2.02	1.02	1.74,	2.30	53
	5	4.77	1.38	4.27,	5.27	32
	6					0
	7	1.42	0.54	1.30,	1.54	85
	8	0.77	0.23	0.75,	0.79	408
Colville	2	0.93	0.20	0.90,	0.96	167
	3	1.23	0.35	1.15,	1.31	83
	4	2.14	1.11	1.77,	2.51	37
	5	5.27	1.95	4.74,	5.80	55
	6	5.63	2.38	3.93,	7.33	10
	7	2.12	1.05	1.94,	2.30	138
	8	0.89	0.34	0.86,	0.92	485
Cradock Channel	2	1.04	0.28	0.90,	1.18	17
	3	1.37	0.29	1.21,	1.53	15
	4	2.87	0.96	2.41,	3.33	19
	5	4.51	1.41	4.09,	4.93	47
	6	5.58	2.21	5.27,	5.89	193
	7	2.97	1.08	2.79,	3.15	138
	8	1.13	0.39	1.06,	1.20	132
Te Anaputa	2	1.01	0.26	0.94,	1.08	54
	3	1.36	0.28	1.25,	1.47	26
	4	2.13	0.72	1.65,	2.61	11
	5	4.86	1.29	4.56,	5.16	72
	6	7.73	3.42	7.12,	8.34	124
	7	3.18	1.34	2.92,	3.44	102
	8	0.97	0.25	0.90,	1.04	57
			MALE			
Cradock Channel	5	0.90	0.38	0.82,	0.98	99
	6	1.02	0.42	0.95,	1.09	127
Te Anaputa	5	0.99	0.34	0.89,	1.09	50
	6	1.01	0.35	0.93,	1.09	85

Figure 17 shows that the large range of maturity indices in ripe females was not caused by any correlation of maturity index with length of fish.

LENGTH AT MATURITY

Length-frequency distributions of each sex in each of the sampling areas were combined for the months of August to December 1969, inclusive, to provide information on length at sexual maturity. Results are shown in Fig. 18. The period August to December was chosen because spawning females first appeared in the Craddock Channel and Te Anaputa samples in August, and the peak of the 1969-70 spawning season was during December 1969. Thus the pre-spawning stages of fish becoming sexually mature for the first time could be expected to be most easily recognised during these months.

Female

Virgin females caught in the Firth of Thames from August to December 1969 ranged in fork length from 14 to 28 cm; that of the smallest sexually maturing specimen was 22 cm. The shortest 1-cm length group in which more than 50% of the sample were sexually mature was 23 cm in fork length.

Fork length of virgin females from the Colville area ranged from 15 to 26 cm, and that of the smallest sexually maturing specimen was 21 cm. At 24 cm in fork length more than 50% of the length group were found to be sexually mature.

Only one virgin female was taken from each of the Cradock Channel and Te Anaputa areas. That from Cradock Channel had a fork length of 20 cm, and the Te Anaputa specimen had a fork length of 21 cm. The smallest sexually mature specimens from both of these areas were 21 cm in fork length.

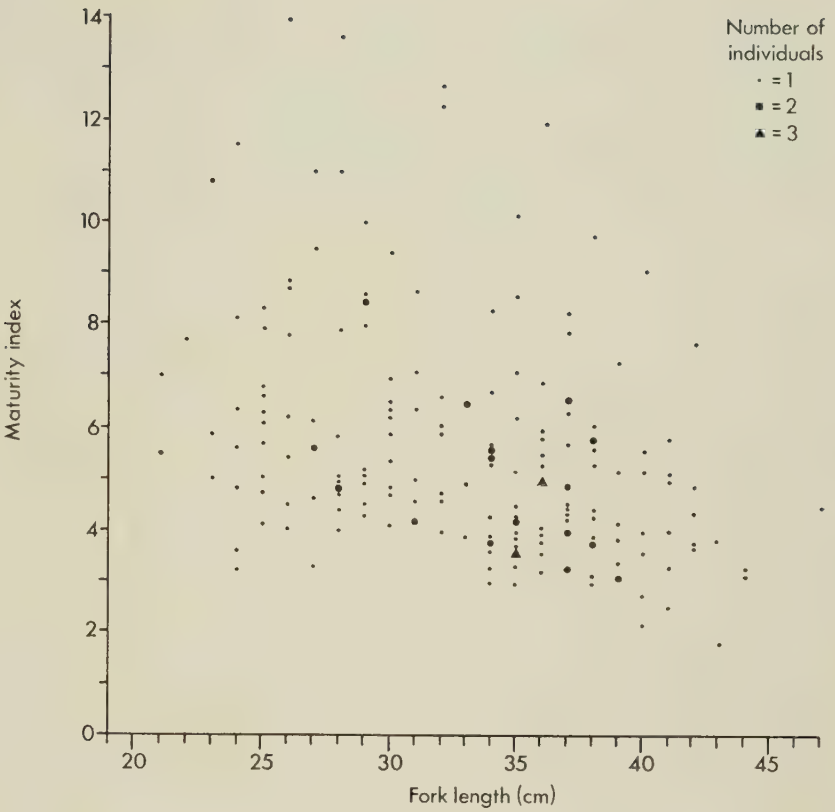


Fig. 17: Maturity indices of spawning (stage 6) females caught in Cradock Channel during the sampling period, December 1968 to March 1970.

Male

Though few male fish were taken from the Firth of Thames area, the virgin males ranged in fork length from 15 to 26 cm and the smallest maturing male was 25 cm.

The catch of virgin males was much greater in the Colville area, where they ranged in fork length from 17 to 24 cm. The smallest maturing male was 20 cm in fork length and the shortest 1-cm length group in which more than 50% of the specimens were sexually mature was 23 cm in fork length.

As with females in the same area, very few virgin males were caught in the Cradock Channel and Te Anaputa areas. Two virgin males, one of 21 cm in fork length and one of 22 cm, were caught in Cradock Channel, and four virgin males, two of 20 cm, one of 21 cm, and one of 22 cm in fork length, were caught in the Te Anaputa area. The smallest sexually maturing males in both areas were 20 cm in fork length.

AGE AT MATURITY

Samples used to establish the age at which gurnard become sexually mature were taken during the same period as those used for determining length at maturity, that is, August to December 1969 inclusive. (The same reasons for choosing this period apply—the greatest likelihood of identifying virgin fish which are about to mature for the first time.)

Because of the confusion caused by the change in age group designation on 1 December (the "birthday" of red gurnard in the Hauraki Gulf) of fish belonging to the same year class it was decided, for the study of age at maturity, to neglect age groups as such and consider the approaching or current summer as being the first, second, third, or any other since the fish was spawned. In fact fish in the study which were approaching, or had just started, their first summer after being spawned belong to the 1968-69 year class (spawned in the spring-summer of 1968-1969); those approaching, or into, their second summer after being spawned belong to the 1967-68 year class, and so on.

Results

The total number of fish belonging to each spawning group, or year class, in the samples taken during the period August to December 1969 and the percentages of these fish which were either virgin or sexually mature are tabulated (Table 9). Areas and sexes have been kept separate in the table.

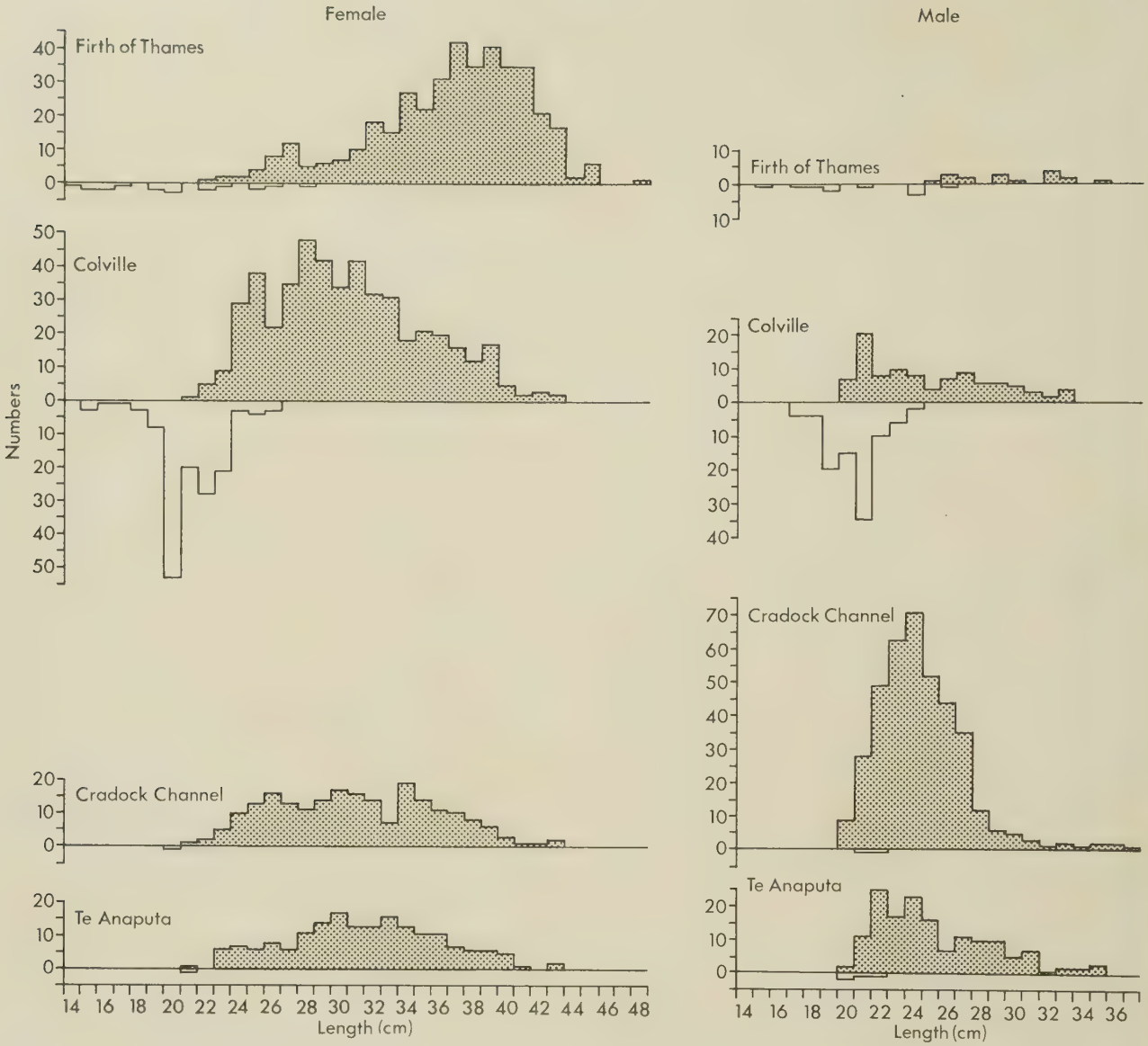


Fig. 18: Combined length-frequency distributions of the catches of virgin (shown in white) and sexually mature fish (dotted) from August to December 1969, inclusive.

Table 9 shows that no fish which were approaching their first summer after being spawned were taken in the catches in Cradock Channel and Te Anaputa. A few fish from this spawning group (the 1968-69 year class) were caught in the Firth of Thames and Colville areas, where they were 100% virgin.

Fish approaching their second summer after being spawned (the 1967-68 year class) were caught in all areas. In-shore catches (Firth of Thames and Colville) of this year class form a group in which less than 60% were sexually mature, and off-shore catches (Cradock Channel and Te Anaputa) make a group in which more than 80% were sexually mature.

Essentially the same two groupings apply to fish approaching their third summer after being spawned. Except for females of the spawning group caught in the Colville area, which were 100% sexually mature, more than 90% but less than 100% of the year class were sexually mature in the in-shore group, and in the off-shore group 100% of the year class were sexually mature.

All fish of both sexes which were approaching their fourth summer after being spawned were found to be sexually mature in all areas.

Figure 19 shows that for both sexes of the 1967-68 year class there is some difference between the length distributions of those becoming sexually mature and those remaining virgin. The mean fork length of virgin females in the sample was 21.2 cm and that of mature females was 24.7 cm. For virgin males the

TABLE 9: Total number of fish belonging to each spawning group, or year class, in samples taken between August and December 1969 and the percentages of them virgin or sexually mature.

Summer since being spawned	Firth of Thames Virgin %	Firth of Thames Mature %	Firth of Thames No.	Colville Virgin %	Colville Mature %	Colville No.	Cradock Channel Virgin %	Cradock Channel Mature %	Cradock Channel No.	Te Anaputa Virgin %	Te Anaputa Mature %	Te Anaputa No.
					FEMALE							
First	100	0	7	100	0	4	0	0	0	0	0	0
Second	43	57	21	56	44	78	8	92	13	17	83	6
Third	2	98	100	0	100	127	0	100	68	0	100	55
Fourth	0	100	87	0	100	87	0	100	49	0	100	49
					MALE							
First	100	0	3	100	0	1	0	0	0	0	0	0
Second	83	17	6	65	35	40	11	89	19	11	89	18
Third	9	91	11	7	93	29	0	100	84	0	100	41
Fourth	0	100	8	0	100	10	0	100	31	0	100	22

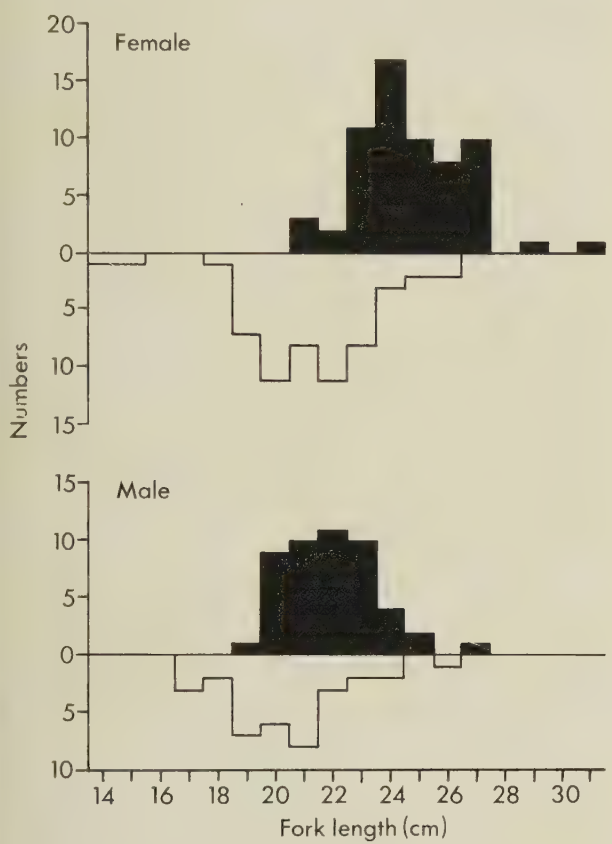


Fig. 19: Length-frequency histograms of virgin (shown in white) and sexually mature (black) male and female fish from all sampling areas combined which were caught during the period August to November 1969 and which were approaching their second summer after being spawned, that is, the 1967-68 year class.

value was 20.3 cm and for mature males it was 22.0 cm. The long spawning season may well explain these length differences between virgin and mature fish. The larger fish are probably older than the smaller, though belonging to the same year class, and therefore have had longer to mature during the optimum summer growth periods. That is, a fish spawned in November would be expected to be larger than one spawned in January of the same spawning season because it would have been actively feeding earlier during its first summer, the best growth period. Therefore by the next January the November-spawned fish, with 14 months' growth, would be much larger and therefore more mature than the January-spawned fish with 12 months' growth.

SPAWNING SEASON, SPAWNING GROUND, AND MIGRATION

The spawning season of a unit stock of a fish species is determined by a study of the seasonal occurrence of spawning fish (stage 6 in the gonad maturity scale) in the catches from the stock. The stock of a species may be migratory for spawning and it is important to determine whether this is so. Migration will affect catch rate; therefore as well as the reproductive state of the fish, the population density, as indicated by catch rates, should be studied to provide information on the pattern of migration.

On spawning grounds, where spawning fish obviously congregate, catch rates of such fish may be expected to be high during the spawning season. However, if some ripe fish are also taken at this time on grounds where non-spawning fish normally reside, they could contribute to a substantial percentage of the total catch rate from those grounds without being sufficiently abundant numerically to affect the reproduction of the total stock materially. For this reason the study of seasonal catch rates by stage of gonad maturity is most important and should not be neglected in favour of a consideration of percentage of occurrence of gonad stages alone. If a species is known to be non-migratory for spawning, a study of percentage of occurrence of spawning fish in the

catches may be adequate to provide information on spawning season. The extent of adequacy will depend on such factors as spawning behaviour other than migration which may alter the catchability of the fish.

The spawning ground of a fish stock is the area where spawning fish abound for either a short period (a short-lived spawning season) or a long period (an extended spawning season).

In the present study early analysis of data on seasonal distribution of fish in different stages of gonad development and their catch rates in the different sampling areas of the Hauraki Gulf suggested that migratory behaviour was likely. Thus the determination of relative abundance of gonad maturity stages by area and time became most important. Therefore only catch rate data have been considered in detail.

Because of their relevance to the study of spawning migration, catch rates of the following groups were considered separately:

1. All sexually mature fish.
2. Spawning fish.
3. Fish in the pre-spawning and post-spawning stages of maturity.
4. Virgin fish.

The catch rates discussed below are based on total numbers of fish at each gonad maturity stage in the whole catch.

Total Catch Rates of Sexually Mature Fish

The following catch rates suggest a seasonal "see-saw" movement of fish from the in-shore to the off-shore grounds and return. For the inner Gulf maximum catch rates were recorded during winter and minimum during late summer-autumn, and for the outer Gulf maximum catch rates were found during summer and minimum during winter.

Female. Figure 20 shows that the maximum catch rate of mature females in the inner Gulf areas occurred during the winter months of August 1969 in the Firth of Thames and July 1969 in the Colville area. The peaks were preceded by a generally steady increase in catch rate from a minimum during April 1969 in the Firth of Thames and February 1969 in the Colville area. However, because the catch rates from February to April 1969, inclusive, in the Firth of Thames were all at about the same level, it can generally be assumed that the catch rates of mature females in the Firth of Thames and Colville areas were low during the late summer in 1969. The winter peaks in catch rate were followed by a generally steady decline, except for "aberrant" low figures in September 1969 in the Firth of Thames and August 1969 in the Colville area. These low levels could be the key to a time scale for the rate of migration of female fish; this point will be discussed later. New low rates for the following year were reached during summer (January 1970 for the Firth of Thames and March 1970 for Colville).

In the Cradock Channel area the total catch rates of mature female fish had the opposite trend to that of the Firth of Thames-Colville areas during the same period. The maximum catch rate was found during the summer months of January and February 1969 and again in December 1969. The January-February peak was followed by a somewhat irregular decreasing trend which reached a minimum during June 1969 before a steady increase to the December 1969 peak.

The catch rates for mature females in the Te Anaputa area were too irregular to be interpreted. This also applies to the male data discussed below. However, according to the local knowledge of Gulf fishermen, catches in this area are greatly affected by changing hydrographic conditions, notably sea state and turbidity and the phase of the moon.

Male. The catch rates of mature male fish (Fig. 20) for the Firth of Thames and Colville areas showed the same seasonal trends as those of female, but were lower.

The catch rates of mature male fish in the Cradock Channel area did not show any seasonal trend, though there were some erratic fluctuations possibly due to sampling variations.

The Te Anaputa male catch rates were almost as irregular as those of females from the same area, except that there was a suggestion of declining catches from summer to winter with an increase to the following summer.

Catch Rates of Spawning Fish

Consideration of the catch rates of spawning fish (stage 6 in the gonad maturity scale), in particular, offered evidence of an off-shore spawning ground (Table 10 and Fig. 20). If this is so, it is the likely cause of the seasonal see-saw effect between the total catch rates of mature fish in the in-shore and off-shore sampling areas.

Female. Spawning females were recorded only during February 1969 in the Firth of Thames. The incidence of spawning females in the Colville area was also low, a few being taken in December 1968 and January 1969 and rather more in September 1969. A small number of spawning females were also taken in November and December 1969.

In the Cradock Channel catches the pattern was much different. Spawning females were taken in all months except July 1969, though during autumn and winter (March to August 1969, inclusive) the catch rates were low. Summer peaks in the catch rate of spawning fish were recorded in January 1969 and again in December 1969. There was a fairly steady build-up from August to the December peak, followed by a sharp drop in January 1970.

The catch rate pattern of spawning female fish in the Te Anaputa area appears anomalous in relation to the peak in August 1969. This peak is very high not only for the area in general, but also for the month in which it occurred. If the high value of the peak is discounted, the pattern is a more reasonable one in which spawning fish first occurred in August 1969, rose to a summer peak during December 1969, then began to fall, probably reaching zero by April 1970. This latter assumption is supported by the very low catch rate in February 1969 and the zero catch in March 1969.

Male. No spawning males were recorded in the Firth of Thames. They occurred in the Colville area in fairly small numbers in summer and autumn of 1968-69 (December, January, March, and April) and in much higher numbers in October 1969. However, no spawning females were taken from the area in October 1969; so the contribution of these males to the reproduction of the Hauraki Gulf gurnard stock at that time would have been nil.

In Cradock Channel spawning males were present in all months except March 1970. The catch rate was moderate during December 1968 and January-February 1969, then rose to a peak in March 1969, which preceded a sudden decline, the declining trend continuing until August 1969. A steady increase then became apparent from the very low catch rate in August to a summer peak in December 1969, which was followed by a sudden drop in January 1970 and total absence in March 1970.

The catch rate of spawning males in the Te Anaputa area declined steadily from January 1969 to a minimum in May and to nil in June, July, and August. Spawning males reappeared in October 1969 and reached a peak in December, which was followed by a steady decline to a minimum in March 1970.

Catch Rates of Pre-spawning and Post-spawning Stages

Female. If the catch rates of the pre-spawning stages (2, 3, 4, and 5), spawning (6), and post-spawning stages (7 and 8) of females in each of the sampling areas are examined together by month, as set out in Table 10, further evidence of an off-shore migration for spawning activity becomes apparent. The data from the initial appearance of stage 2 females preparatory to the 1969-70 spawning season are considered.

In the Firth of Thames the first pre-spawning stages before the 1969-70 spawning season were found in the June 1969 catch. The total catch of females in that month was composed of fish at stages 2, 3, and 4, the catch rate of stage 2 being higher than that of stage 3, which in turn was higher than that of stage 4, an expected distribution of pre-spawning stages. During July stage 5 fish were also found and the catch rates graded from highest for stage 2 to lowest for stage 5. In August the catch rate of stage 5 fish was greater than that of stage 4, but less than that of stages 2 and 3, and no spawning (stage 6) fish were caught. Thus the emphasis in catch rate was clearly shifting towards the late pre-spawning stages. The total catch rate of mature fish dropped sharply during September, and, though a small return of spent (stage 7) fish occurred, no spawning females were taken. During October the catch rate of pre-spawning stages (2, 3, and 4) improved and the catch rate of stage 7 increased slightly. In November the catch rate of spent fish increased further, and some resting (stage 8) fish appeared; only a few stage 5 fish were taken and no other pre-spawning stages were caught for the first time since the end of the 1968-69 spawning season. Apart from an occurrence of stage 2 fish in December 1969, which may equally have been misidentified stage 8 fish, pre-spawning stages remained absent from the catches for the remainder of the sampling period. At no time during the period from June 1969 to November 1969 were any spawning females caught in the area. This could mean only that the fish, though maturing in the area, were moving elsewhere to spawn and later returning in a spent condition.

A similar pattern was found with the catch rates of pre-spawning stages in the Colville area, though some spawning fish were taken there. Stage 2 females first appeared in May 1969, a month earlier than in the Firth of Thames. By June stage 3 were also present and by July some stage 5, but the catch rate of stage 2 still continued dominant. In August the catch rate of stage 5 had increased over the level of the previous month, though no spawning females were taken and the total catch rate of mature fish had fallen sharply. During September a few spawning fish were taken, but their catch rate was very low compared with that of the pre-spawning and spent stages, which had now appeared. By October the pre-spawning stages had largely disappeared from

Firth of Thames
Colville
Total
Stage 6
Female
Female
Male
Male
No sample
No sample
No sample
No sample
Catch rates (numbers per hour)
Sea bottom temperature (°C)
500
100
50
10
5
1
0·5
0·1
22
20
18
16
14
12
D J F M A M J J A S O N D J F M
1968
1969
1970

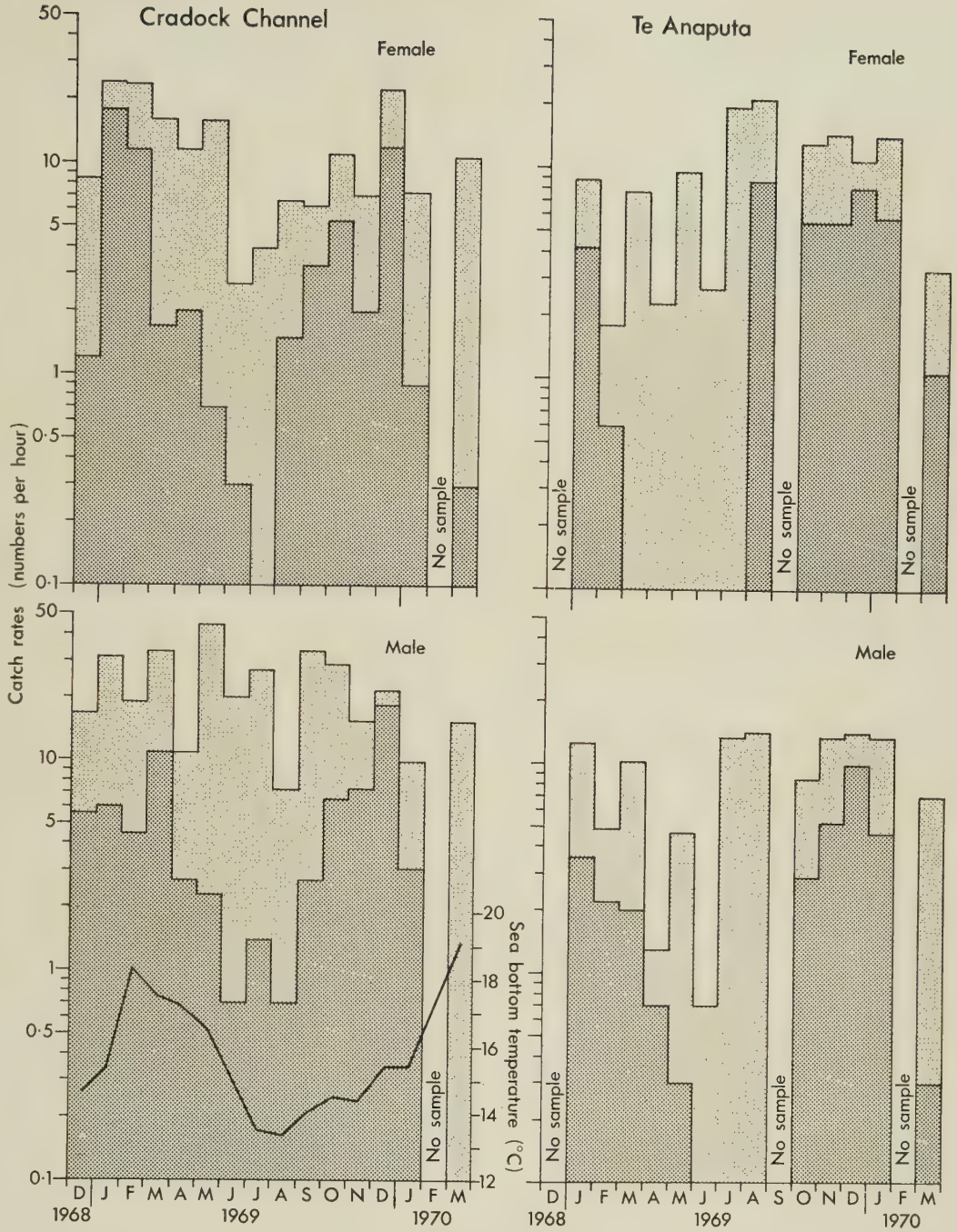


Fig. 20 (left and above): Catch rates (numbers of fish per hour trawled) of all sexually mature fish (shown in lighter tone) and spawning fish (darker tone) and monthly sea bottom temperatures. Scale is logarithmic. Because bottom temperature data for the Te Anaputa area were not complete, they have not been included.

the catches and were replaced by spent and resting females, which continued to be the dominant stages until the end of the sampling programme in March 1970. The minor occurrence of stage 2 again in December in this area may also have been misidentified stage 8 fish.

In Cradock Channel the pre-spawning stage 2 also first appeared in June, though the catch rate was very low. The other pre-spawning stages were all found in July, though also in limited quantities. During August the catch rate of the early pre-spawning stages 2 and 3 had declined in favour of the later stages 4 and 5, and, further, some spawning fish were also taken, at a catch rate only slightly less than that of stage 5 animals, though, as noted in the discussion on total catch rates of mature fish, the

TABLE 10: Catch rate (numbers per hour trawled) of sexually mature fish by stage of gonad maturity.

	1968						1969							1970	
Stage	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Mar
Firth of Thames															
							FEMALE								
2	20.5	17.6	0.3	0	0	0	66.1	70.3	49.8	2.7	24.9	0	2.5	0	0
3	19.5	6.4	0	0	0	0	12.6	30.3	55.8	2.3	8.4	0	0	0	0
4	10.5	7.6	0.3	0.3	0.3	0	0.5	13.1	21.7	1.0	2.2	0	0	0	0
5	5.0	0.8	1.3	0	0.3	0	0	3.4	27.6	1.0	0	1.7	0	0	0
6	0	0	0.3	0	0	0	0	0	0	0	0	0	0	0	0
7	10.5	6.4	6.3	1.3	3.0	8.4	0	0	0	0.7	0.9	8.7	0.5	1.7	0
8	4.0	26.0	33.0	38.7	28.7	61.3	0	0	0	0	0	8.7	16.0	3.0	12.5
							MALE								
2–8	3.5	2.4	1.7	1.7	1.7	3.1	2.7	6.3	3.2	0	0	1.0	1.0	0	0
3–4	4.0	2.0	0	0	0	0	0.5	2.3	2.3	0	2.2	0	0	0	0
5	2.0	0	0	0	0	0	0	0.6	0	0	0.4	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0.4	1.0	0.3	0	0	0	0	0	0	0	0	0	0	0
Colville															
							FEMALE								
2	6.0	0.8	0	0	0	16.0	145.3	208.0	19.0	33.6	0	0	0.3	0	0
3	18.0	3.6	0	0	0	0	7.3	56.0	31.0	36.0	0	0	0	0	0
4	9.0	4.4	0.2	0	0	0	0	0	17.0	16.8	1.6	0	0	0	0
5	4.0	7.6	2.0	1.0	2.0	0	0	3.0	10.0	20.8	6.4	3.4	0.6	0	0
6	0.5	1.6	0	0	0	0	0	0	0	4.8	0	0.9	0.3	0	0
7	12.0	36.8	2.5	9.0	4.0	1.5	0	0	0	16.8	29.6	7.4	5.1	1.4	0
8	13.0	30.8	18.2	99.5	197.8	115.5	0	0	0	0	46.4	13.5	10.6	4.9	4.2
							MALE								
2–8	2.5	4.4	1.2	11.0	31.8	18.0	28.7	48.0	0	9.6	4.8	0.9	0.6	0	1.0
3–4	4.5	0	0	0	0	0	0	34.0	8.0	12.0	0	0	0	0	0
5	1.5	0	0	0.5	0	0	0	0	1.0	2.4	0	0	0	0	0
6	2.0	0.4	0	0.5	1.1	0	0	0	0	0	10.4	0.3	0	0	0
7	1.5	0	0.8	1.0	1.1	8.5	0	0	0	0	23.2	1.8	0.6	0.9	0
Cradock Channel															
							FEMALE								
2	0.8	0	0	0	0	0	2.0	1.4	0.7	0	0	0	0	0	0
3	0.8	0	0	0	0	0	0	1.7	0.7	0	0.6	0.3	0	0	0
4	1.6	0.2	0	0	0	0	0	0.6	1.5	0	0.6	0	0	0.3	0
5	2.0	3.0	1.0	0.7	0	0	0	0.3	2.3	0.7	0.9	0.6	0.8	0.6	0.9
6	1.2	17.8	11.5	1.7	2.0	0.7	0.3	0	1.5	3.3	5.4	2.0	12.0	0.9	0.3
7	1.6	1.5	3.5	7.3	4.3	1.7	0	0	0	0.2	3.7	3.1	8.5	4.0	3.1
8	0.4	1.8	7.5	6.3	5.3	13.3	0.3	0	0	0.3	0	1.1	1.2	1.7	6.6
							MALE								
2–8	0	0	2.2	2.0	1.7	32.0	16.3	5.4	0.8	1.0	0.6	1.1	0	1.4	11.1
3–4	5.2	9.0	0.8	0	0	0	1.3	13.4	3.0	17.7	10.9	0	0	0	0
5	6.4	13.8	6.0	1.7	0	0	0	7.1	2.3	11.0	10.0	1.7	0	0	0
6	5.6	6.0	4.5	11.0	2.7	2.3	0.7	1.4	0.7	2.7	6.6	7.4	18.8	3.1	0
7	0	2.5	5.5	18.3	6.7	10.3	1.3	0	0.3	1.0	0.6	5.4	3.0	5.4	4.6
Te Anaputa															
							FEMALE								
2		0.6	0	0	0	0	2.7	14.0	0.4		0.3	0	0	0	0
3		0	0	0	0	0	0	5.8	4.4		0	0	0	0	0
4	No	0.8	0	0	0	0	0	0	3.6	No	0	0	0	0	0
5	sample	10.6	0	0	0.3	0	0	0	4.4	sample	0.9	4.7	0	1.3	0
6		4.2	0.6	0	0	0	0	0	8.9		5.7	5.7	8.3	6.0	1.1
7		2.2	0.6	5.6	0.3	1.0	0	0	0		6.9	3.7	2.6	4.3	1.1
8		0.6	0.6	2.2	1.7	8.7	0	0	0		0	0.7	0.3	2.7	1.1
							MALE								
2–8		0.2	0	0.2	0.3	3.0	0.7	7.0	1.8		0	0	0	1.3	5.7
3–4	No	4.0	0.3	0	0	0	0	6.2	11.6	No	2.9	1.7	0.6	0	0
5	sample	4.0	0	0	0	0	0	0	0.9	sample	2.9	6.0	3.1	0.7	0
6		3.6	2.2	2.0	0.7	0.3	0	0	0		2.9	5.3	10.0	4.7	0.3
7		0.8	2.5	8.0	0.3	1.3	0	0	0		0	0.7	0.6	7.0	1.1

catch rate was still very low. From September 1969 until the end of the sampling period the catch rates of the pre-spawning stages remained negligible, but that of spawning fish increased to a peak in December, then declined. This distribution appears to indicate that most spawning females had come from another area, presumably the inner Gulf. After the December peak in catch rate of spawning females the catches of spent and resting fish did not maintain the earlier catch rate of spawning fish. This further suggested that migration was the reason, with post-spawning females moving away from the area.

Catch rates for the Te Anaputa area did not offer much evidence for migration, as the catch rate of pre-spawning stages between June and August could probably have accounted for the catch rate of spawning females in August. Apart from the reduced total catch rate of mature fish in March 1970, there was little to suggest a post-spawning movement from the ground.

Male. The catch rates of pre-spawning (2-8, 3-4, and 5), spawning (6), and post-spawning (7) stages of males in each of the sampling areas (Table 10) show that they, like the females, migrate off shore for spawning.

In the Firth of Thames catch rates of pre-spawning and post-spawning stages were very low during all months, and no spawning males were caught at all; presumably they emigrated to spawn.

Males in the Colville area were caught in considerable numbers in the pre-spawning stages of maturity, but few spawning fish were taken except during October, when no spawning females were present to contribute to the reproduction of the population.

The catch rates of males in the pre-spawning stages in Cradock Channel were moderate from May 1969 to October. The presence, also, of spawning fish during these months and in November could have been the result of the maturation of a resident stock. However, the peak catch rate of spawning males in December 1969 was not preceded by an expected moderate catch of stages 3-4 and 5 fish in November; nor were any pre-spawning stages caught in December. This suggested that the peak catch rate of spawning fish in December was from a pre-spawning group which had immigrated to the area. The pattern of catch rates for males in the Cradock Channel area suggests a partly resident stock of fish which spawns over an extended period and which is joined by some migrants from the in-shore areas during the peak of the spawning season in summer.

The theory proposed above for Cradock Channel could also be applied to the Te Anaputa area, where there was a build-up in catch rates of pre-spawning stages from July until the first occurrence of spawning males in October. This increased catch rate of pre-spawning fish does not precede the peak catch rate of spawning males in December; nor does it support the January catch of spawning males.

Distribution of Virgin Fish

The catch rates (numbers per hour) of virgin fish by sampling area and sex are shown graphically (Fig. 21).

An outstanding feature is the very low catch rate of virgin fish of both sexes in the Cradock Channel and Te Anaputa areas. Mean monthly catch rate over the 16-month sampling period was 0.3 virgin female and 0.6 virgin male fish per 1 hour of trawling in Cradock Channel and 0.5 virgin female and 0.5 virgin male fish in the Te Anaputa area. During the same period the comparable figures for the Firth of Thames were 6.2 female and 2.0 male and for Colville 19.0 female and 19.2 male.

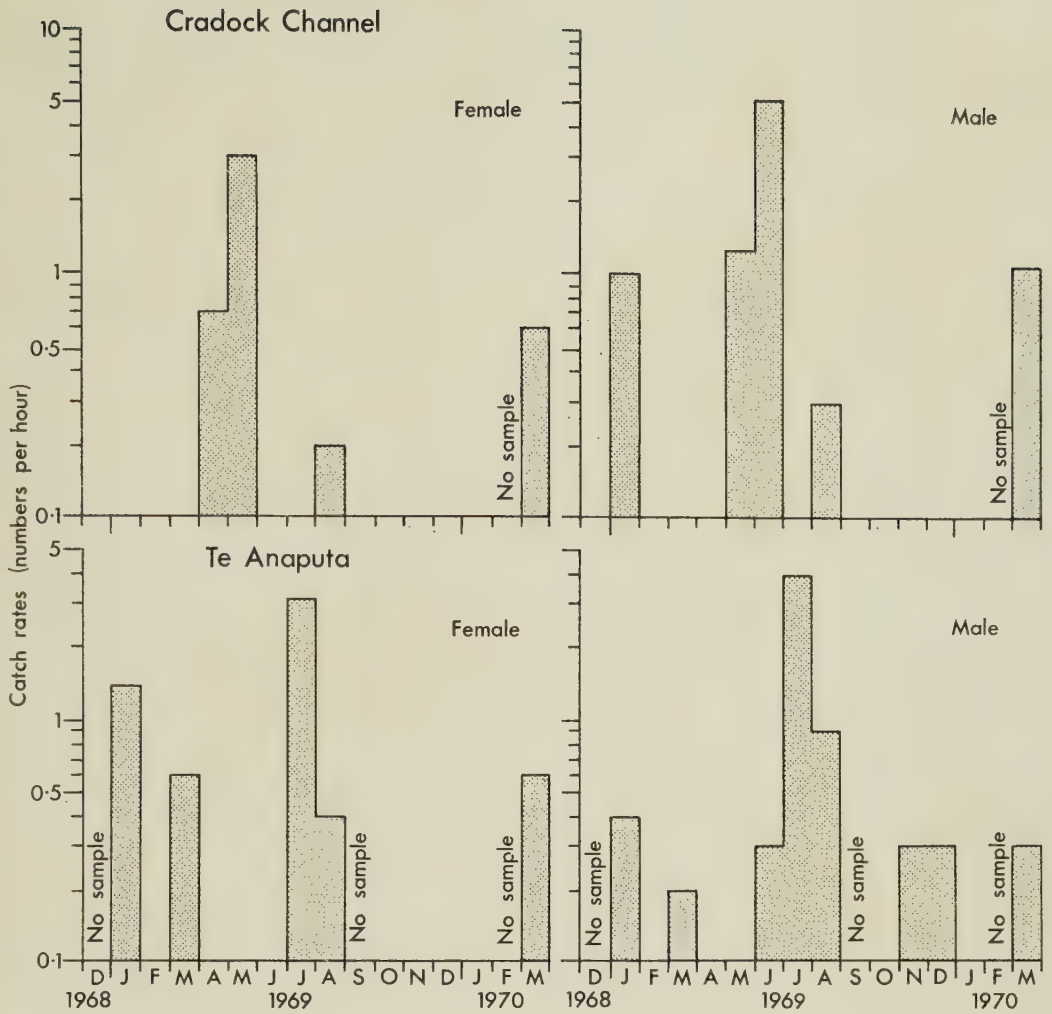
Although no very small fish were caught in quantity in any of the four sampling areas, the catch rates for Colville suggest that it lies nearest to a major nursery ground. The Firth of Thames area, though having a somewhat lower catch rate of virgin fish than Colville, is also probably near to a nursery ground and possibly the same ground. The probable site of a nursery ground is discussed later in this section in relation to local current and tide systems.

The percentages of virgin fish in the overall mean catch rates of both virgin and mature fish in each area for the 16-month sampling period are tabulated (Table 11).

These percentage figures are further evidence for an off-shore spawning migration. The proportion of virgin fish on the proposed spawning ground (Cradock Channel) is very small; the spawning areas are stocked mainly by mature fish which must therefore have migrated from elsewhere. Conversely, because the proportion of virgin fish, especially males, on the in-shore grounds is considerably higher than on the off-shore grounds, this is the likely source from which the sexually mature specimens which stock Cradock Channel are derived.

The mean catch rate of virgin male (19.2/h) and female (19.0/h) fish in the Colville area indicates a sex ratio of 1:1 for virgin fish. Such a ratio would be expected on a nursery ground where mortality should be equal for both sexes if their behaviour is the same. It is not until behavioural differences between the sexes develop with maturity, as they apparently do in red gurnard, where males appear to stay on the spawning ground longer than females, or even

Fig. 21 (above and right): Catch rates (numbers of fish per hour trawled) of virgin fish by sampling area and sex. Scale is logarithmic.



permanently, to the detriment of their growth rate (see "Age and Growth"), that differing mortality rates could be expected to alter sex ratios from 1:1.

An effort was made to find a nursery ground for juveniles among the bays and around the islands of the eastern inner Gulf from Te Kouma Harbour to Colville Bay. Other likely areas, including the western shore of the Firth of Thames and the bays of the western coast of Great Barrier Island, were also investigated. The two beam trawls and the prawn trawl, described in the section "Sampling Method", were used in areas where the full-sized otter trawl could not be shot.

Red gurnard of about 15 cm in fork length or less were sought to correspond with the small 0+ age group (see "Age and Growth"), which was uncommon in trawl samples from the main sampling areas. Except for one red gurnard of 11 cm in fork length caught off Saddle Islet, Kikowhakarere Bay, west of Coromandel, the search was fruitless, though the trawl gear was known to be working satisfactorily, as numbers of flatfishes, gobies, and sandfish (*Hemerocoetes*), all of which are bottom-dwelling species, were taken.

However, Dr J. A. Colman, of the Fisheries Research Division, caught a number of juvenile red gurnard while he was sampling for two species of flounders. Details of these catches are given (Table 12). For sampling he used an otter trawl with a 1-in.-mesh cod-end liner and tickler chain.

TABLE 11: Percentages of virgin fish in the mean catch rates of both virgin fish and mature fish in each area for the period of study.

Area	Percentages of virgin fish	
	Female	Male
Firth of Thames	11	39
Colville	17	51
Cradock Channel	2	3
Te Anaputa	4	5

These catches came from a single trawl station in each area; so it is reasonable to assume that the numbers are a measure of relative abundance. Therefore the results of the catches made by Dr Colman may support the suggestion that there is a major nursery near the Colville Bay area.

The virtual failure to catch juvenile red gurnard in surveys made during the present study raises the possibility that they inhabit grounds unsuitable for trawling, for example, rough ground or weed-covered ground which may provide cover. This possibility is likely in view of the results of beach seining I did at Days Bay, Wellington Harbour, in 1968. A small seine net was set immediately beside the pilings of the Days Bay wharf, and a few small gurnard were taken. When the net was reset less than 6 m away from the wharf no gurnard were taken; yet another set beside the wharf yielded a few more juvenile fish.

Significance of the Te Anaputa Sampling Area

The two in-shore sampling areas (Firth of Thames and Colville) and the off-shore Cradock Channel area can conveniently be fitted into one system on the basis of reproductive behaviour. The fourth sampling area (off-shore Te Anaputa) has been difficult to resolve in terms of the migratory system proposed for the other three. The difficulty may be because Te Anaputa has a different status from the other areas. One suggestion is that it is a "staging area" between the in-shore areas and an off-shore spawning ground and hence has a transient and variable population. A second proposal is that the fish in the Te Anaputa area are part of a separate unit stock, possibly from the western Bay of Plenty.

Rate of Migration

As stated previously, the aberrant low catch rates of sexually mature females recorded during August 1969 in the Colville area and September 1969 in the Firth of Thames might be interpreted as markers which provide a time scale for the rate of migration of females. Details of the catch rates are shown (Fig. 20).

To understand the significance of these low catch rates one needs to examine the total catch rates of sexually mature females in the Cradock Channel, Colville, and Firth of Thames areas during May to October, inclusive (Fig. 22).

The relatively high catch rate figure for May in Cradock Channel was followed by a sudden decrease in June, when the minimum catch rate for the area was recorded. The maximum catch rate for the Colville area was recorded during July and this, in turn, was followed by the aberrant low rate in August, which was the minimum winter catch rate for the area. During August the maximum catch rate for the Firth of Thames was also recorded.

TABLE 12: Catch numbers of juvenile fish taken in three areas.

Location	Date	Depth (m)	Mean length (cm)	Length range (cm)	No.
Orere Point	Dec 1969	0	9	0	1
"Dab Patch"	Jul 1970	31	8.8	7.5–11.5	6
Colville Bay	Sep 1970	14–20	10.1	8.0–11.5	23

It is suggested that a major emigration of females from Cradock Channel took place sometime near the end of May or beginning of June. About 6 to 8 weeks later, in July, the fish had arrived in the Colville area, and about 6 weeks later, in August, they had reached the Firth of Thames. The in-shore, post-spawning migration of about 50 nautical miles had therefore taken 12 to 14 weeks.

The maximum catch rate in the Firth of Thames during August was itself followed by the aberrant low rate of September, the minimum spring catch rate for the area. In the same month an increase in catch rate was recorded for the Colville area, when the maximum spring catch rate was reached. This was followed by a decreasing catch rate during October, when the maximum spring catch rate was recorded for Cradock Channel.

Therefore it is further suggested that a spawning migration began in early September from the Firth of Thames, the fish reaching the Colville area during September and Cradock Channel during October, a total elapsed time of about 7 weeks.

The shorter time for the migration to the spawning ground compared with the post-spawning migration is reasonable, as the fish would be in better condition, and therefore better able to make a rapid journey, at this time than they would after spawning.

The pattern and timing of migration are summarised (Table 13). (Catch rates refer to total catch rates of sexually mature females.)

It is not suggested that all fish moved the whole distance from Cradock Channel to the Firth of Thames and vice versa. The generally higher total female catch rate for the Colville area, as compared with the Firth of Thames, may indicate that many fish migrate only as far as the former area after spawning. Nor is it suggested that all fish migrate at the same time, only that a "pulse" of migration, to or from the spawning ground, took place over the months mentioned.

Figure 20 shows that the minimum bottom temperature in the Firth of Thames was reached during July (12.3°c) and that there was only a slight rise in

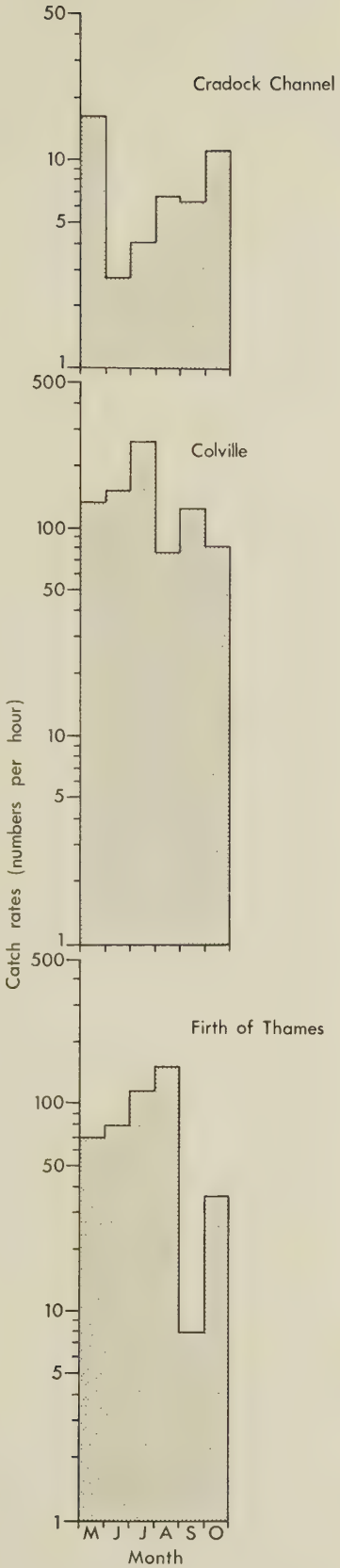


Fig. 22: Catch rates (numbers of fish per hour trawled) of sexually mature females for May to October 1969, inclusive. Scale is logarithmic.

TABLE 13: Pattern and timing of spawning migrations in three areas.

Area	Emigration from spawning ground	Immigration to spawning ground
Cradock Channel	(Winter) June (minimum catch rate)	(Spring) October (maximum spring catch rate)
	↓	↑
Colville	July (maximum catch rate)	October (decreasing spring catch rate)
	August (minimum winter catch rate)	September (maximum spring catch rate)
	↓	↑
Firth of Thames	August (maximum catch rate)	September (minimum spring catch rate)

August (0.1°C to 12.4°C). However, by September it had risen by 0.9°C to 13.3°C. This rise after the winter minimum corresponded with the start of the migration of females from the Firth of Thames towards the spawning ground (Table 13). Rising temperatures may therefore be the stimulus for migration.

Variations in Spawning Season

Table 10 and Fig. 20 show that the peak of the 1968-69 spawning season occurred later in summer than the peak of the 1969-70 spawning season. A cause for this phenomenon is suggested by the data on sea bottom temperatures (Fig. 20). The December 1968 bottom temperature in the Firth of Thames was 1.2°C less than that for December 1969. The same applies for the Colville area, and the Cradock Channel bottom temperature in December 1968 was 0.8°C less than in December 1969. For all three areas the December 1968 bottom temperatures had almost been reached by November 1969.

Because the pre-spawning stages of both sexes began to appear in the catches before the winter minimum bottom temperature was reached, rising temperatures could not have been the stimulus for the start of the spawning cycle. However, the higher temperatures earlier in 1969-70 could have encouraged a more rapid rate of development to the ripe stage and hence an earlier peak in spawning activity.

SEX RATIO

Sex ratios were calculated for sexually mature fish from the total numbers of males and females in the

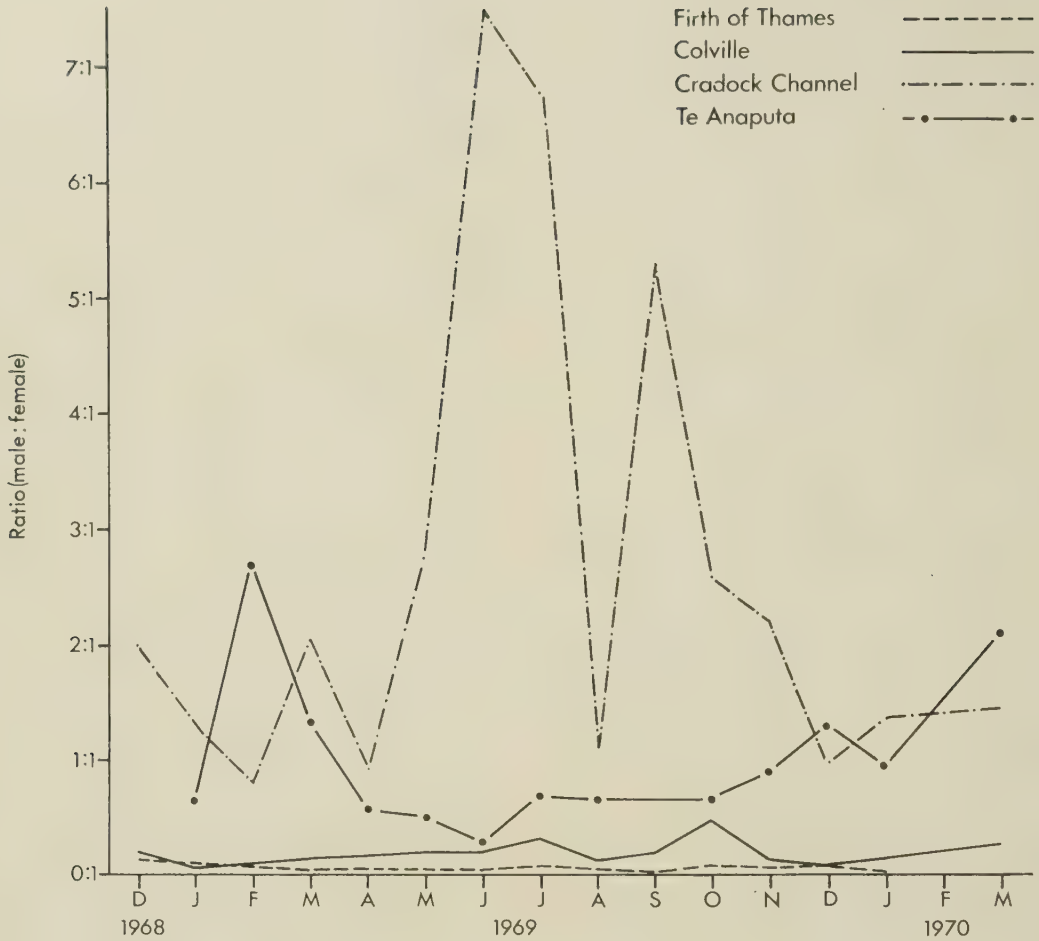


Fig. 23: Sex ratio of mature fish (male : female) by month and sampling area.

catches. The numbers of each sex and ratios are presented (Table 14).

Figure 23, illustrating the sex ratios, lends further support to the theory that females migrate into the Cradock Channel area during the spawning season and away from it after spawning.

The ratio of males to females in Cradock Channel lay between 2:1 and 0.8:1 during the 1968-69 summer, with its January peak of spawning activity. As females moved away from the area the ratio soared, reaching 7:1 in June and July 1969, before dipping as females began to return to the area with the approach of the 1969-70 spawning season, when the sex ratio reached 1:1 at the peak of spawning activity in December 1969.

The curve of sex ratios for Cradock Channel (Fig. 23) is somewhat complicated by the dip in August 1969, but the total of mature fish, both male and female, was very low during that month. Moreover, the catch rate of sexually mature male fish in August 1969 was atypical of the catch rates during the 3 months preceding and after August (Fig. 20), which therefore suggests that this dip was due to random sampling variation.

In the other sampling areas males formed a significant proportion of the catch only in Te Anaputa, and here the variation in ratio of male to female with time of year suggests that females moved away from the area during summer and returned during winter. This may indicate a migration to deeper water for spawning, but because the total catch rates of sexually mature fish in this area were very erratic, as discussed above, there is no additional evidence to support the theory.

The catch rate data on sexually mature fish, the percentage of occurrence of gonad developmental stages by month, and the sex ratios all suggest that mainly the females are migratory.

DISCUSSION

Harden Jones (1968) stated that generally migration patterns of fish are believed to be related to the

TABLE 14: Numbers of sexually mature male and female fish and male : female ratio by area, month, and year.

		Firth of Thames			Colville			Cradock Channel			Te Anaputa		
Year	Month	M	F	Ratio M:F	M	F	Ratio M:F	M	F	Ratio M:F	M	F	Ratio M:F
1968	Dec	18	141	0.13	24	125	0.19	42	21	2.00	No sample		
1969	Jan	12	162	0.07	12	214	0.06	125	96	1.30	63	94	0.67
1969	Feb	8	125	0.06	8	93	0.09	76	94	0.81	16	6	2.67
1969	Mar	6	121	0.05	27	219	0.12	99	48	2.06	51	39	1.31
1969	Apr	5	97	0.05	152	919	0.17	33	35	0.94	4	7	0.57
1969	May	7	157	0.04	53	265	0.20	133	48	2.77	14	29	0.48
1969	Jun	6	146	0.04	43	229	0.19	60	8	7.50	2	8	0.25
1969	Jul	16	205	0.08	82	267	0.31	95	14	6.79	53	79	0.67
1969	Aug	12	336	0.04	9	77	0.12	44	40	1.10	32	49	0.65
1969	Sep	0	24	0	30	161	0.19	100	19	5.26	No sample		
1969	Oct	6	82	0.07	48	105	0.46	101	39	2.59	30	47	0.64
1969	Nov	3	57	0.05	10	82	0.12	55	25	2.20	41	45	0.91
1969	Dec	2	38	0.05	4	59	0.07	87	90	0.97	50	39	1.28
1970	Jan	0	14	0	3	22	0.14	35	26	1.35	41	44	0.93
1970	Mar	0	24	0	4	17	0.24	55	38	1.45	25	12	2.08

pattern of water currents. Young stages, especially eggs and larvae, drift with the current to the nursery ground; spawning fish migrate against the current to the spawning ground; and spent fish return to the feeding ground with the current. The nursery and feeding grounds may or may not be the same ground. Harden Jones also noted (page 7): ". . . the advantage might lie not so much in the choice of a spawning area in its own right, but for its position in relation to a favourable nursery area to which the young are carried passively by the prevailing current. In this case the spawning migrations made by the mature fish must be related, in some way, to the drift of their young." Thus the mechanism of spawning migration is used to maintain a population of fish within its geographical limits against the dispersing effect of currents. The drift of eggs and larvae has been termed a denatant movement and the return of spawning fish to the spawning ground against the current has been termed a contranatant movement (Meek 1915a, 1915b).

The earliest person to have realised the need for a contranatant spawning migration appears to have been Fulton (1897), who showed by drift bottles that some of the plaice eggs spawned in the Moray Firth and Firth of Forth, Scotland, would have been carried southward along the coast. He suggested a compensatory return of mature plaice for spawning, which was later proved true by tagging experiments (Fulton 1920).

Migrations by triglid species in coastal waters of countries other than New Zealand have been recorded by Fulton (1897, 1899), McIntosh (1900), Meek (1915b), and Marshall (1946). These migrations have been shown to be associated largely with spawning activity. However, apart from Meek the authors do not directly acknowledge a link between spawning migrations and water currents.

The waters of the Hauraki Gulf, especially the outer Gulf, are influenced by the south-easterly flowing East Auckland Current, which extends from North Cape to East Cape.

The usual maximum flow rate of the current is from 1 to 1.5 knots, but near Cradock Channel it is said to attain a rate of 2.5 to 3 knots after strong northerly winds (Hydrographic Department 1958). This work further states (page 157): "With a rising tide the north-west-going stream enters Colville Channel and sets along the south-western side of Great Barrier Island as far as False Head, where it meets the south-going stream that enters Hauraki Gulf from the northward; these streams attain a rate of about 1 knot." On page 164 it says: "In the vicinity of Cape Barrier and Cape Colville the tidal streams set westward with a rising tide and eastward with a falling tide; they attain a rate of from 2 to 3 knots at springs."

Drift cards released by Brodie (1960, Fig. 3a) in the western end of Colville Channel during summer were recovered on the eastern side of the inner Gulf, about the Coromandel area.

Garner (1961) reported the recovery near Coromandel of a card released off North Cape during summer 1955. His Fig. 4 suggests that he believed this card to have passed through Cradock Channel.

Figure 24 shows the supposed track of drift cards as shown by Brodie and Garner.

The above account of currents and tides illustrates the possible course of drift of red gurnard eggs and larvae on the eastern side of the Hauraki Gulf. If we accept the hypothesis of Harden Jones (1968)

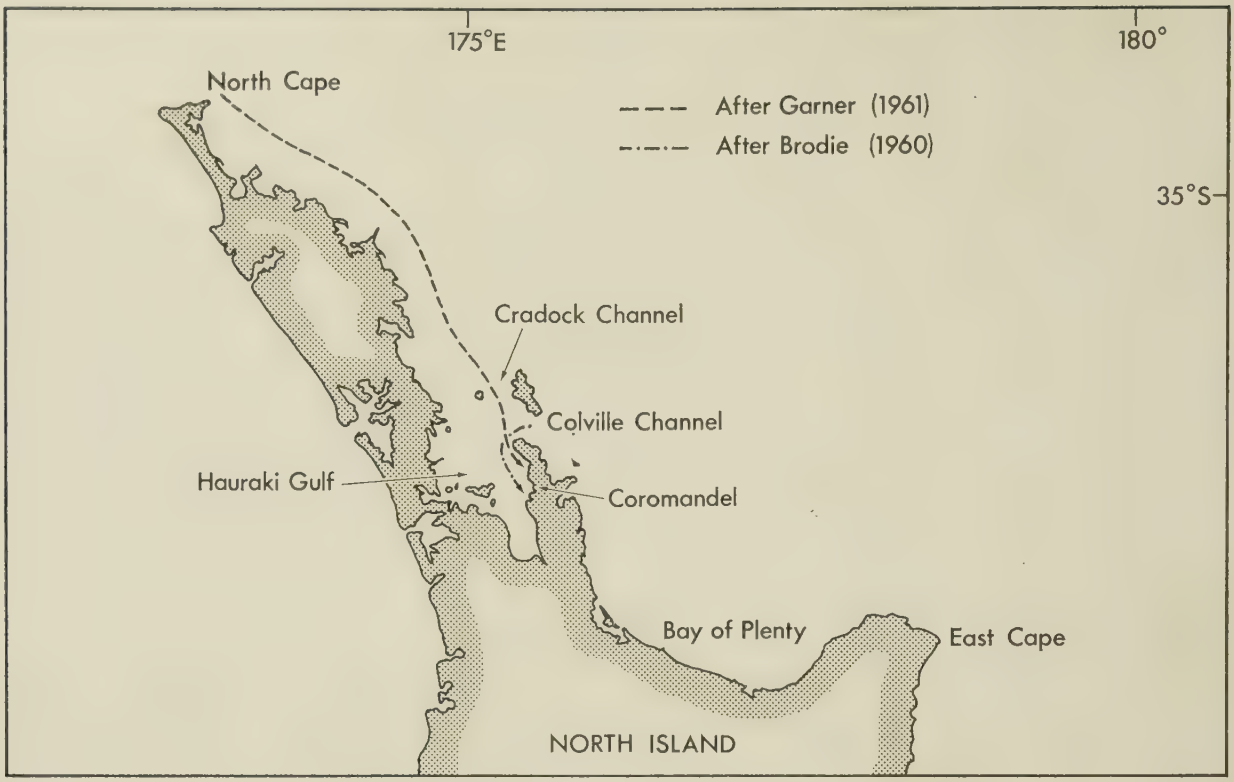


Fig. 24: The supposed tracks of drift cards as shown by Garner and Brodie.

that spawning fish undertake a contranatant migration to a spawning ground because of its position in relation to a favourable nursery area, the pattern of red gurnard distribution in the eastern Hauraki Gulf becomes logical. The catch rate of virgin fish in the Colville sampling area has shown that the area is probably close to a nursery ground, certainly the closest to such a ground of the four sampling areas, with the Firth of Thames area the next closest. The pattern of water currents illustrated by Brodie and Garner has shown that mature gurnard would have to migrate to the Cradock Channel area to spawn in order to stock the eastern inner Gulf embayments with larvae and juveniles.

YIELD PER RECRUIT ISOPLETH DIAGRAMS

INTRODUCTION

As stated by Ricker (1958, page 205): "The goal of most work on growth and mortality in fish populations has been an assessment of the yield of the stock at different levels of fishing effort, or with different size limits for recruitment."

Without estimates of population size or annual number of recruits, and separate estimates of natural and fishing mortalities, no prediction of sustainable yield can be made for red gurnard in the Hauraki Gulf. However, the growth parameters W_∞, K, and t_0, for which likely values have been calculated, were substituted in the yield equation of Beverton and Holt (1957), also known as the dynamic pool model (Dickie 1962), by use of a range of values for instantaneous natural and fishing mortalities and a range of values for recruitment to the fishery (age at first capture). The range of mortality values used are those that could be expected to bracket the actual values in the fishery. In this way yield per recruit isopleth diagrams have been constructed to predict yields per recruit of red gurnard at different levels of fishing intensity and age at first capture for a range of natural mortality coefficients.

The Beverton and Holt yield equation requires the following basic assumptions to be made:

(a) Natural mortality among fully recruited year classes is constant; that is, mortality does not vary with age or population density.

(b) Recruitment is "knife-edge"; that is, fish suddenly become catchable at some specific size or age. (This is not so in many fisheries, as vulnerability usually increases over a range of sizes and ages. The problem is minimised in practice by making the age at recruitment equal to the middle of the range of increasing vulnerability.)

(c) Fish follow an invariable growth pattern conforming to the von Bertalanffy growth curve.

If the notation of Gulland (1969) is used, Beverton and Holt's model states that R fish enter a fishing area at age t_r and are subjected to the instantaneous rate of natural mortality, M, until age t_c, when they become vulnerable to the fishing gear in use and are subjected to the instantaneous rate of fishing mortality, F, as well. Thereafter they grow, die naturally, or are removed by fishing up to some maximum age, t_L, at which time they have, for all practical purposes, been removed from the population. The yield (in weight) per recruit is then given by:

$$Y_w / R = Fe^{-M(t_c - t_r)} W_\infty \sum_{n=0}^{3} \left\{ \frac{U_n e^{-nK(t_c - t_0)}}{F + M + nK} \left[1 - e^{-(F + M + nK)(t_L - t_c)} \right] \right\}$$

where Y_w is yield in weight; R is the number of recruits; F is the instantaneous fishing mortality coefficient; M is the instantaneous natural mortality coefficient; W_∞ is the asymptotic weight (from the von Bertalanffy equation); K is a constant from the von Bertalanffy equation; t_0 is the apparent age at apparent zero length or weight (from the von Bertalanffy equation); $U_0 = +1$, $U_1 = -3$, $U_2 = +3$, $U_3 = -1$ (that is, numerical terms resulting from expansion of the von Bertalanffy cubic equation representing weight at age); t_r is the age of recruitment to the fishing ground; t_c is the age at entry to the fishery (age at which fish become vulnerable to the gear); t_L is the age at which contribution to the catch ceases.

(Yield per recruit curves will correspond to total yield curves only if recruitment is independent of stock density. Because density-independent recruitment is open to question, yield per recruit curves should not be interpreted as total yield curves (Hennemuth 1961).)

In the present study it has been shown that male red gurnard are fully recruited on to the fishing grounds at age 2+ years and females at age 3+ years. However, the midpoint of recruitment on to the fishing grounds could be considered as being at age 2+ years for females, as this age group was caught in considerable quantity on all sampling grounds (Fig. 12); in fact it was the dominant age group on the Colville ground. Males of age group 1+ years were common on the Colville ground, but were not common on the Firth of Thames, Cradock Channel, and Te Anaputa grounds (Fig. 12).

In view of the above the age of recruitment on to the fishing grounds, t_r, is considered to be 2 years for both males and females in the yield per recruit calculations.

The greatest age of any fish caught during the study was 15 years, and this value has been used for the maximum age, t_L.

Values for the total instantaneous mortality rate, Z, were calculated for each sex (see "Mortality and Survival"). They were:

Female

$\hat{Z} = 0.65$

with 95% confidence limits: $0.48 \leqslant Z \leqslant 0.83$

Male

$\hat{Z} = 0.60$

with 95% confidence limits: $0.52 \leqslant Z \leqslant 0.69$

For calculations of yield per recruit it has been assumed that natural mortality does not exceed one-half of the total mortality. Therefore values of M from 0.1 to 0.3, in steps of 0.05, have been used with values of F from 0.1 to 3, in steps of 0.1, for ages at first capture, t_c, from 2 to 10 years, inclusive. Values of F up to the very high value of 3 were included partly to ease the drawing of isopleths.

The values of W_∞, K, and t_0 used were those given in the section "Length-weight Relationships and Condition". These are:

	W_∞ (g)	K	t_0
Female	469	0.641	0.189
Male	233	0.569	−0.522

RESULTS

Figures 25 and 26 illustrate the yield per recruit isopleths calculated for female and male red gurnard respectively.

The figures show that yields per recruit generally increase rapidly as fishing mortality increases from 0.1 to between 0.5 and 1.0. Thereafter the yields per recruit increase only slowly as fishing mortality increases. Age at first capture must be increased appropriately to realise the maximum yield per recruit for a given fishing mortality.

Selected sections through the surfaces represented in Figs. 25 and 26 are shown in Figs. 27 and 28. The sections have been chosen so that the previously calculated values of $\hat{Z}$ and their 95% confidence limits are covered by the combinations of M and F.

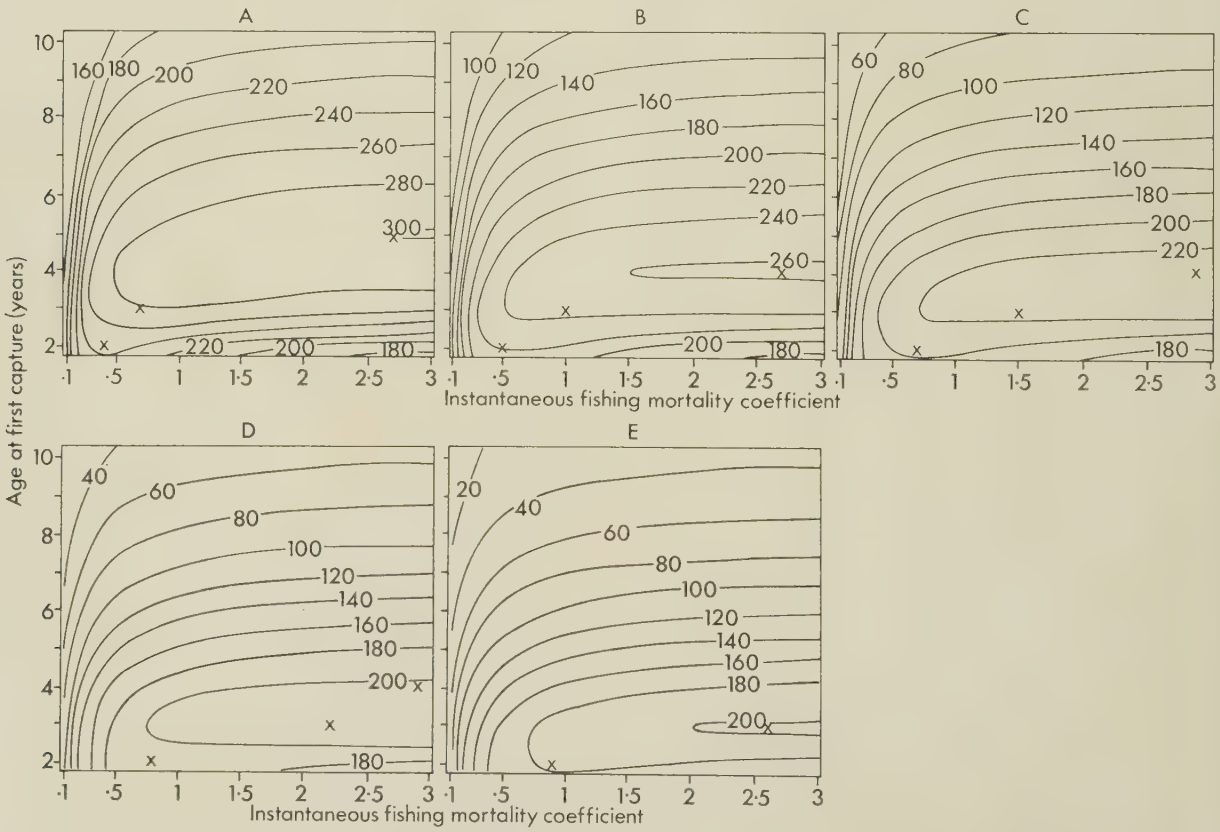


Fig. 25: Yield per recruit isopleth diagrams for female red gurnard at various levels of fishing mortality and age at first entry into the fishery (age at first capture). (Yield is in grams.) A: Instantaneous natural mortality rate, $M = 0.1$. B: $M = 0.15$. C: $M = 0.2$. D: $M = 0.25$. E: $M = 0.3$. The points X show the maximum yield per recruit for given age at first capture up to the age of m aximum possible yield per recruit.

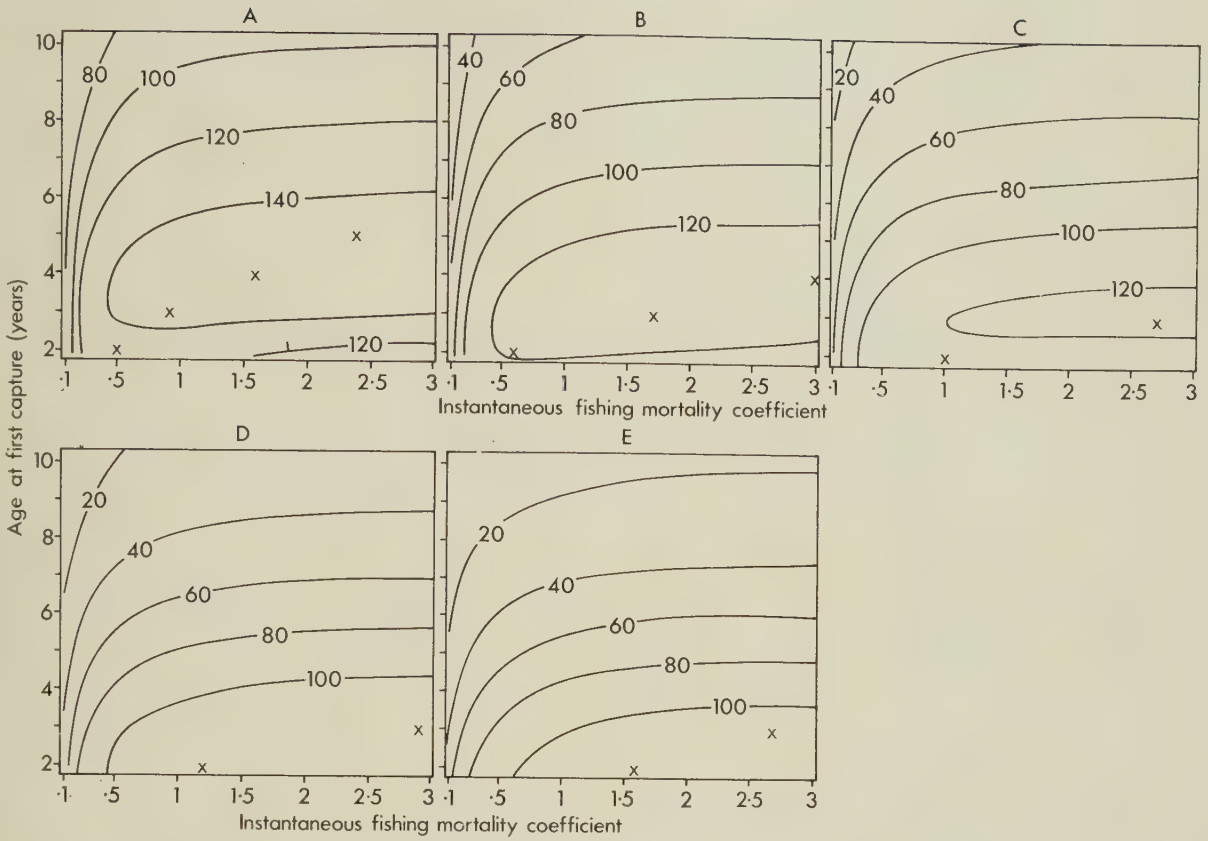


Fig. 26: Yield per recruit isopleth diagrams for male red gurnard at various levels of fishing mortality and age at first entry into the fishery (age at first capture). (Yield is in grams.) A: Instantaneous natural mortality rate, $M = 0.1$. B: $M = 0.15$. C: $M = 0.2$. D: $M = 0.25$. E: $M = 0.3$. The points X show the maximum yield per recruit for given age at first capture up to the age of maximum possible yield per recruit.

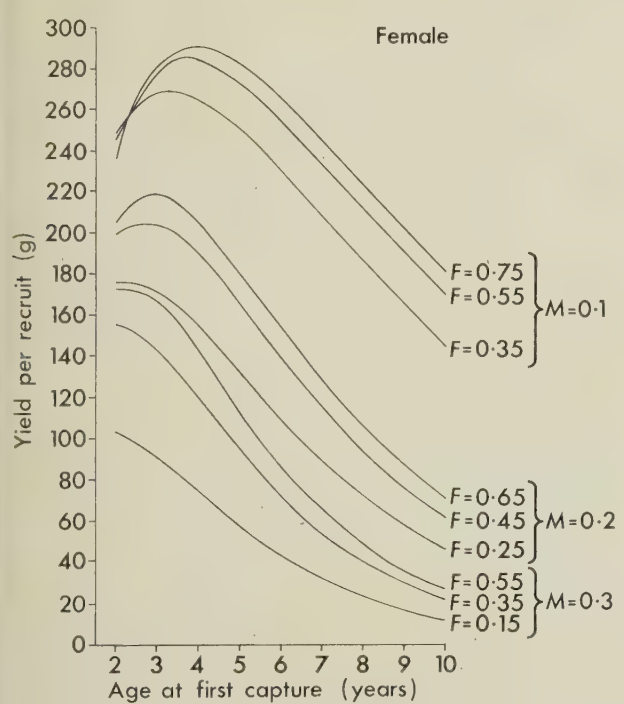


Figure 27 shows for females that if natural mortality is low ($M = 0.1$), age at first capture should lie between about 3.4 years and 4 years for maximum yield per recruit. If natural mortality is higher ($M = 0.2$), age at first capture should lie between 2 years and 3 years for maximum yield per recruit. For still higher natural mortality ($M = 0.3$) female red gurnard should be taken as soon as they are present on the trawling grounds if maximum yield per recruit is to be realised.

Figure 28 shows for males that if natural mortality is low ($M = 0.1$), age at first capture should lie between about 3.2 years and 3.5 years for maximum yield per recruit. For higher natural mortalities male red gurnard should be taken as soon as they are present on the trawling grounds for maximum yield per recruit to be obtained.

DISCUSSION

The escape of small fish from trawl nets in the Hauraki Gulf was investigated by Cassie (1955) with

Fig. 27: Yields per recruit of female red gurnard at various ages at first capture for some likely values of natural mortality (M) and associated values of fishing mortality (F).

nets having cod-ends of 10.2-cm (4-in.), 12.7-cm (5-in.), and 15.2-cm (6-in.) mesh; mesh measurements were taken between opposite knots, inside the knots, with the mesh stretched to its largest dimension. The cod-end mesh size now used by trawlers based at Auckland is 11.4 cm (4.5 in.), though the regulations require a minimum 10.2-cm (4-in.) mesh, which suggests that Cassie's results need some extrapolation to make them applicable to present conditions. However, extrapolation has not been attempted, because Cassie found that his results with the 12.7-cm mesh were anomalous for red gurnard, and the anomaly could not be readily explained. Cassie showed that, with a 10.2-cm-mesh cod-end, the respective lengths at which 90%, 50%, and 10% of red gurnard escape were about 21.1 cm (8.3 in.), 27.9 cm (11 in.), and 34.5 cm (13.6 in.).

Figure 29 shows that very few 1+ and few 2+ females are retained, but considerable numbers of 3+ and most 4+ and older females are retained, by trawl nets with a 10.2-cm-mesh cod-end; the figure also shows that generally no 1+, very few 2+, and few 3+ males are retained by the same trawl nets.

If it is assumed that the 11.4-cm mesh escape curve does not differ greatly from that of the 10.2-cm mesh, the cod-end mesh size in current use is ideal for female red gurnard if their natural mortality is low ($M = 0.1$), but too large if their natural mortality is higher. However, the 11.4-cm mesh is too large for producing the maximum yield per recruit from male red gurnard regardless of their natural mortality rate. This disadvantage with males is offset by their less abundance and the resultant need to protect them to some extent to ensure continued spawning success. Further, it has been shown that males approach their asymptotic length at a relatively early age, many sexually immature fish being large. Therefore any reduction in mesh size may result in a high catch rate of virgin male fish, which would dangerously affect reproduction of the red gurnard stocks.

Also to be considered is the effect of a different mesh size on other species. Because the Hauraki Gulf fishery is mainly a snapper (*Chrysophrys auratus*) fishery, legislation on mesh size should be directed to provide the maximum yield per recruit for this species in particular. (At present the mesh size required to achieve this is unknown.)

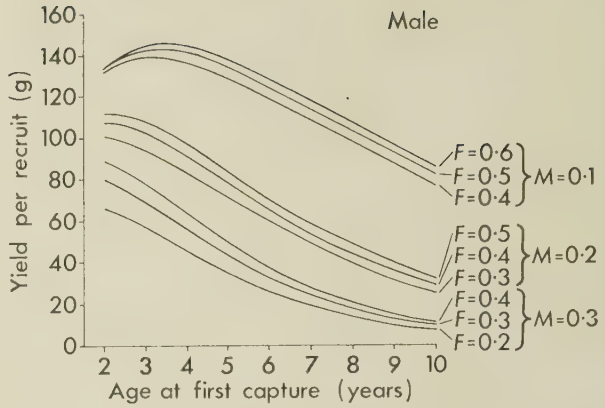


Fig. 28: Yields per recruit of male red gurnard at various ages at first capture for some likely values of natural mortality (M) and associated values of fishing mortality (F).

Allen (1953, page 210) showed that ". . . when the [size] limit is that which gives the maximum yield, the weight of the typical individual fish at the limit is the product of the average weight of fish in the catch and the proportion of the fish passing the limiting size which are ultimately caught". Thus, as noted by Dickie (1962, page 108), ". . . for any fishery, if the composition of the catch is observed, and the fraction of the total mortality which is due to fishing can be measured (by tagging experiments, for example) an immediate appraisal of the fishery may be made. If the weight of fish at the size limit is smaller than the product, then an increase in the size limit would be expected to increase the yield. If it is larger, market or fishing preferences are probably competing with the interests of greatest yield at that fishing intensity, but greater poundage yield could be obtained by catching some smaller fish." Therefore the implementation of a tagging programme to determine fishing mortality would probably be the most profitable line of further research, as it would enable "an immediate appraisal of the fishery" to be made. Tagging would also enable the population size to be determined.

It should also be noted that a minimum size limit for red gurnard of about 30 cm in fork length is often imposed on fishermen by wholesale and retail fish marketers, though the smaller fish caught are used as rock lobster bait. This market preference will have considerable effect on the management of a red gurnard fishery, and the optimum biological yield per recruit may never be attained unless natural mortality proves to be low.

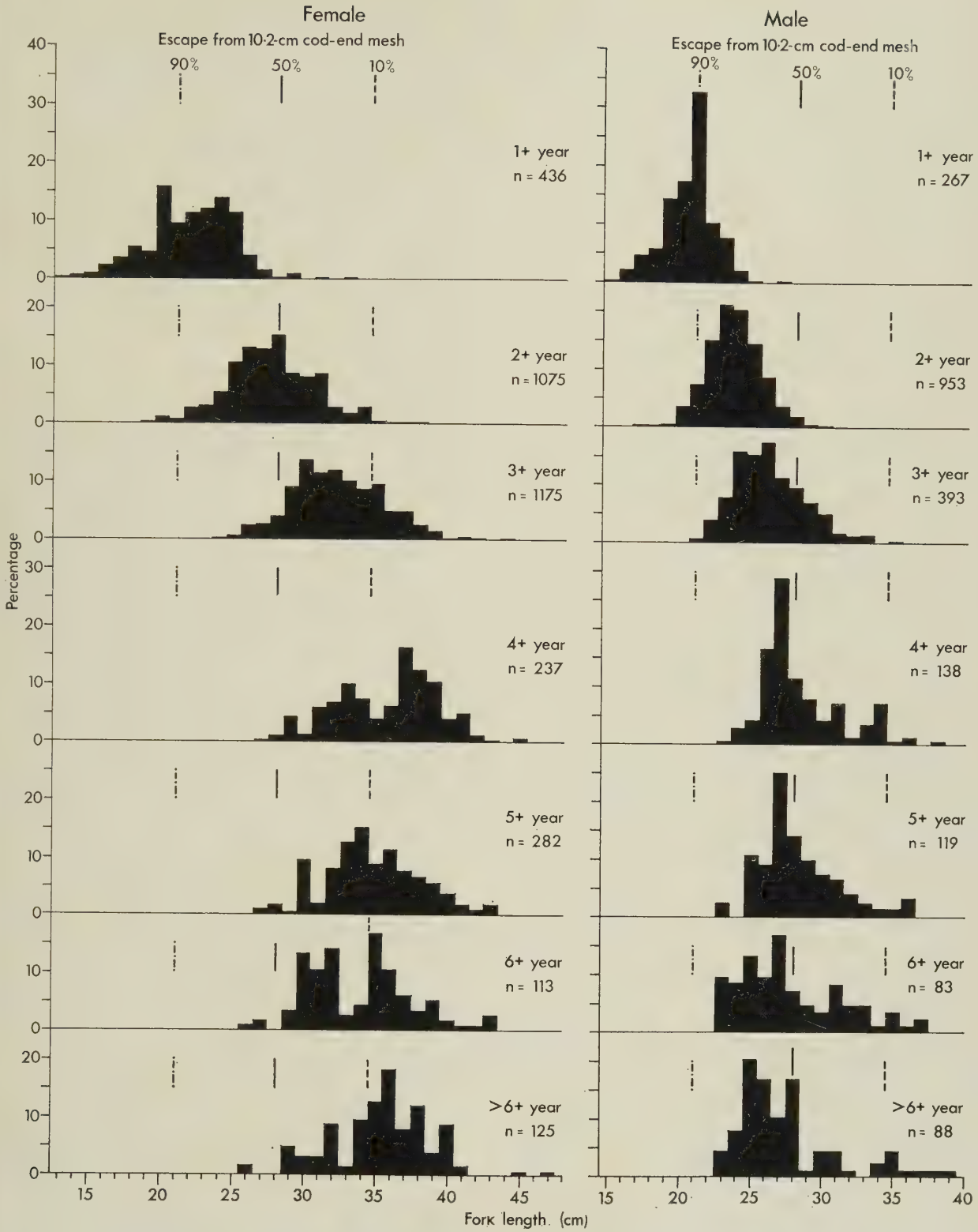


Fig. 29: Length-frequency histograms of each age group from 1+ to 6+ years and the combined length-frequency histogram for fish older than 6+ years, sexes separate, for the catch during the 12 months December 1968 to November 1969.

SUMMARY

Monthly samples of the red gurnard population were taken from four sampling areas in the eastern Hauraki Gulf—Firth of Thames and Colville (inner Gulf) and Cradock Channel and Te Anaputa (outer Gulf). Length-frequency, age-frequency, and age-length distributions and reproductive state of each sex in the catch were determined by a method of stratified sampling.

Otoliths were used for age determination. It was established that hyaline zones were deposited annually and became visible as dark rings after the otolith was broken transversely and the broken end heated in a flame.

Growth equations for each sampling area and sex were calculated by a method which allows any number of data at unequal intervals of time to be used and which gives equal weight to each observation. In all areas it was found that males have a slower growth rate and smaller asymptotic length than do females from the same area. The length of post-2-year-old fish of both sexes was considerably larger in the Firth of Thames area than in the Colville, Cradock Channel, and Te Anaputa areas. Further, there was a marked similarity between the growth curves for each sex in the last three areas. Age-length data from these three areas were combined to provide composite growth curves for each sex which could be used in yield per recruit analyses. Because trawl and Danish seine fishing in the Hauraki Gulf is permitted by regulation only outside the Firth of Thames, this pattern of combination seemed appropriate. The composite growth curves calculated for each sex are:

Female

$$l_t = 36.4\,[1 - e^{-0.641\,(t-0.189)}]\ \text{cm}$$

Male

$$l_t = 28.8\,[1 - e^{-0.569\,(t+0.552)}]\ \text{cm}$$

It is suggested that differences between the growth curves, within sexes, calculated for fish from the Firth of Thames and those from the other sampling areas were a result of spawning behaviour, though the possibility of size selective mortality having an effect on the calculated curves is not excluded.

The von Bertalanffy growth equations calculated for red gurnard from Pegasus Bay, New Zealand, and from the East China and Yellow Sea by other workers apparently showed no difference in growth characteristics between males and females. However, though the asymptotic lengths calculated for the species from these widely separated locations were similar to each other, they were much greater than those calculated for the Hauraki Gulf red gurnard. This may be partly due to differences in growth pattern associated with environmental temperature and partly due to competition, both intraspecific and interspecific.

The length-frequency distributions of males and females in the samples reflected the results of the age and growth study—males generally being distributed at the lower end of the length range.

Sex ratios changed greatly with depth, the proportion of males increasing as depth increased. Sex ratios also varied with time of year, especially in Cradock Channel, where the sexes were about even during the height of the spawning season, but males greatly outnumbered females at other times.

Recruitment to the trawling and Danish seining grounds of the eastern Hauraki Gulf was gradual, with males being fully recruited at 2 years of age and females at age 3 years. There were distinct differences in catch rates of individual age groups between areas within sexes and between sexes within areas. The Colville area had the highest catch rate overall of both male and female red gurnard for all age groups combined.

Catch curves were used to determine instantaneous total mortality rates, Z, for males and females. The calculated rates and their 95% confidence limits were:

Female

$\hat{Z} = 0.65$

95% confidence limits for Z : $0.48 \leqslant Z \leqslant 0.83$

Male

$\hat{Z} = 0.60$

95% confidence limits for Z : $0.52 \leqslant Z \leqslant 0.69$

Length-weight data from gutted fish were analysed in detail by the statistical method of analysis of covariance in an attempt to examine seasonal changes in condition. The heterogeneity of residual variances and regression coefficients between subgroups meant that the adjusted means calculated in the analyses of covariance could not be used as estimates of relative condition. However, an average regression for all red gurnard length-weight data, with the least mean

square deviation from regression, was calculated during the analyses of covariance; this was:

$$\log W = 2.99 \log L - 2.001$$

or $$W = 0.009\,98\, L^{2.99}$$

The regression coefficient did not differ significantly from 3.

The average regression was used to convert the von Bertalanffy equations for rate of growth in length into those for rate of growth in weight:

Female

$$w_t = 469\,[1 - e^{-0.641\,(t-0.189)}]^3 \text{ g}$$

Male

$$w_t = 233\,[1 - e^{-0.569\,(t+0.552)}]^3 \text{ g}$$

Seasonal condition was analysed by calculating ratios of observed to expected weights for individual fish and averaging the results by sex, area, and month. Mean monthly relative condition factors calculated in this way lacked any distinct seasonal trend.

Though the weights of gutted fish were used, relative condition in both sexes varied greatly with stage of gonad maturity, especially for females. Peak condition in females was found in fish at gonad stage 4 (developed), and in males it was found in fish at gonad stage 5 (gravid). Because fish of both sexes at various stages of gonad maturity were found together during a number of months, the analysis of condition by season became less important.

Gonads were readily staged, macroscopically, for maturity according to an eight-point scale for females and a six-point scale for males. Observations suggest that red gurnard are partial spawners. Maturity indices were calculated for all sexually mature females and for gravid and ripe males only.

Male red gurnard reach sexual maturity at a smaller size than do females. The fork lengths at which more than 50% of specimens could be expected to be maturing sexually for the first time were 24 cm for females and 21 cm for males.

Age at first maturity varied with the area from which the fish were taken. No red gurnard became sexually mature in their first summer after being spawned. In the outer Gulf more than 80% of the fish became sexually mature for the first time in their second summer after being spawned, and in the inner Gulf areas less than 60% became mature. More than 90% of fish in all areas were sexually mature in their third summer after being spawned. Sexual maturity was reached earliest by the larger fish of an age group. There was apparently no difference in the age at which the two sexes reach sexual maturity for the first time.

The distribution of spawning fish indicated an off-shore spawning ground in Cradock Channel. Catch rates of sexually mature fish at the various stages of gonad maturity suggested a seasonal migration, especially of females, from the inner Gulf areas to this spawning ground and a corresponding post-spawning migration of spent fish in the reverse direction. Mature males appeared to be at least partly resident on the spawning ground. Rising temperatures may initiate the pre-spawning off-shore migration.

Although spawning males were taken all year round in Cradock Channel, and spawning females virtually all year round, the peak of spawning activity was during the late spring and early summer. Some minor variation in the time of peak spawning activity may be caused by the influence of temperature on the rate of maturation of the gonads.

The distribution and catch rate of virgin fish suggested that the Colville area lay closest to a nursery ground. Very few virgin fish were taken in the outer Gulf.

The proposal that the spawning ground for the eastern Hauraki Gulf red gurnard is sited in Cradock Channel is supported by the tide and current system of the Gulf. Tides and currents would passively carry eggs and larvae from Cradock Channel to a nursery ground in the inner Gulf, probably among the eastern inner Gulf embayments.

The Te Anaputa area was difficult to fit into the migration pattern, but it may be a "staging area" in the migration between the inner Gulf areas and the spawning ground in Cradock Channel. It may also be part of the range of a separate western Bay of Plenty red gurnard stock and consequently not part of the eastern Hauraki Gulf system.

Yield per recruit isopleth diagrams were prepared for likely levels of instantaneous natural mortality rate. Sections through the isopleth diagrams at appropriate levels of fishing mortality suggested that the cod-end mesh size in current use in the Hauraki Gulf (11.4 cm) is suitable for maximum yield per recruit of females if their natural mortality is low ($M = 0.1$), but that it is too large if their natural mortality is higher. However, this mesh size is too large to produce the maximum yield per recruit of males even at low levels of natural mortality, but as the males are less abundant on the trawling grounds, their loss may be necessary to ensure continued spawning success.

The spawning behaviour of red gurnard is the single most important feature of their biology. This behaviour greatly influences recruitment, growth, and mortality—the three most important aspects of fisheries management—of the species in the Hauraki Gulf.

ACKNOWLEDGMENTS

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APPENDIX

MONTHLY TEMPERATURE PROFILES

Monthly temperature profiles from December 1968 to January 1970 and for March 1970 are shown (Figs. 30A-E) for the eight hydrographic stations marked in Fig. 1. (Station 1 is in the Firth of Thames and station 8 at the northern end of Cradock Channel.) Isotherms are at 0.5°c intervals.

Highest surface temperatures were reached during January in 1969 and 1970 and persisted into March. Highest bottom temperatures were reached during March.

A well-developed midwater thermocline was apparent during January in both 1969 and 1970. However, the temperatures of December 1968 were already being reached in November in 1969.

Minimum bottom temperatures were reached during August with a temperature inversion, of about 1°c, occurring in shore.

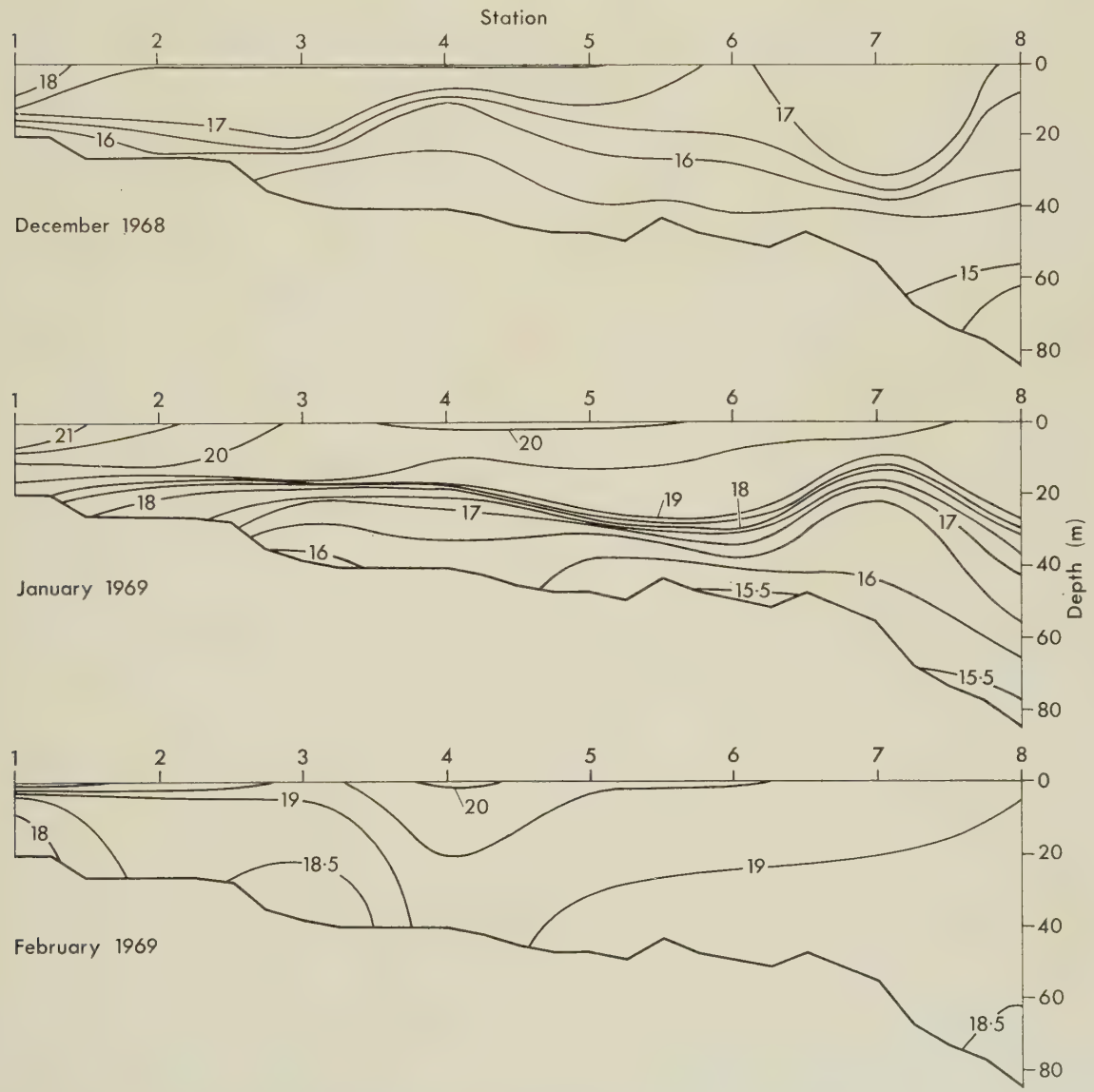

Fig. 30A: Temperature profiles from December 1968 to February 1969.

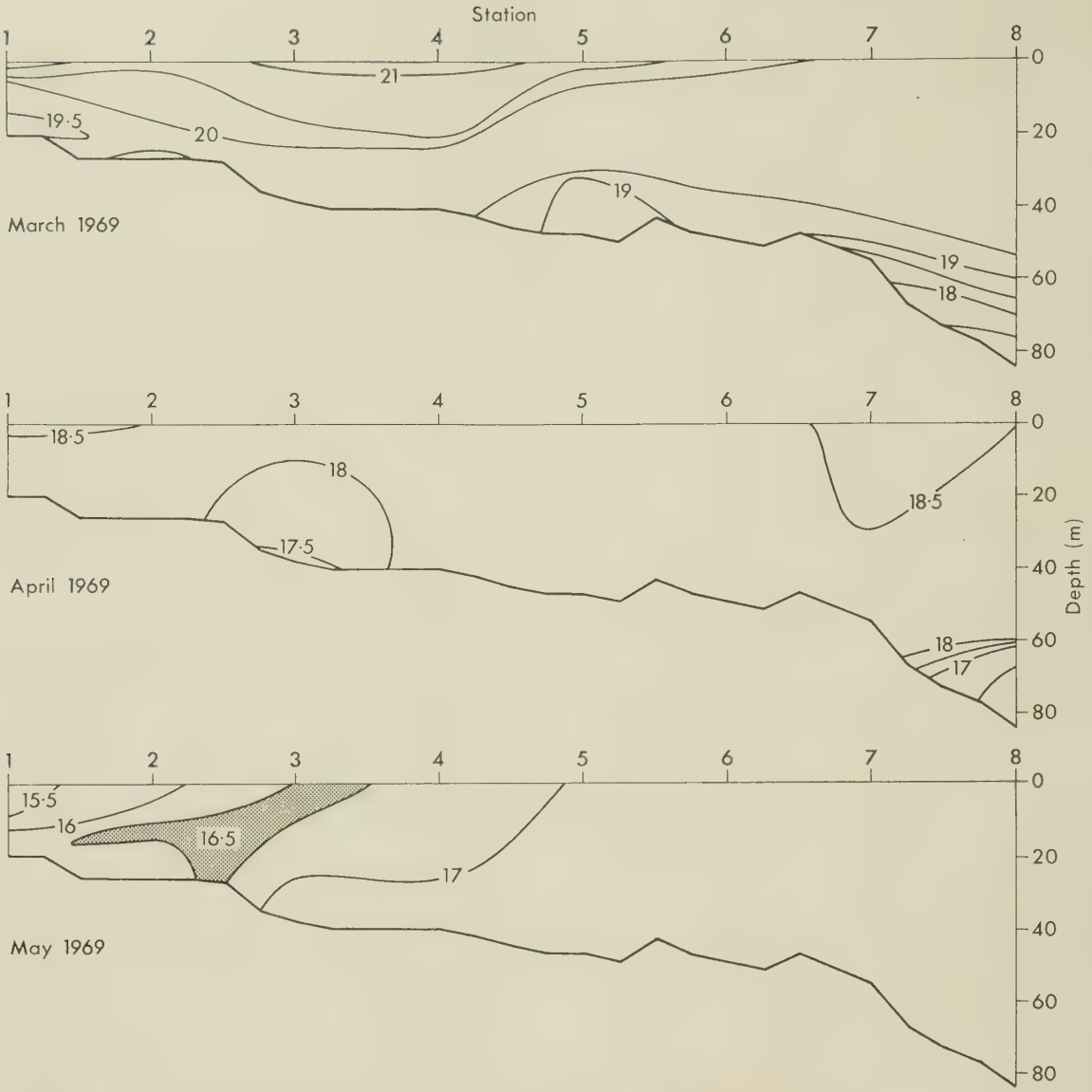

Fig. 30B: Temperature profiles from March to May 1969. The dotted area represents a zone of supposed isothermal water.

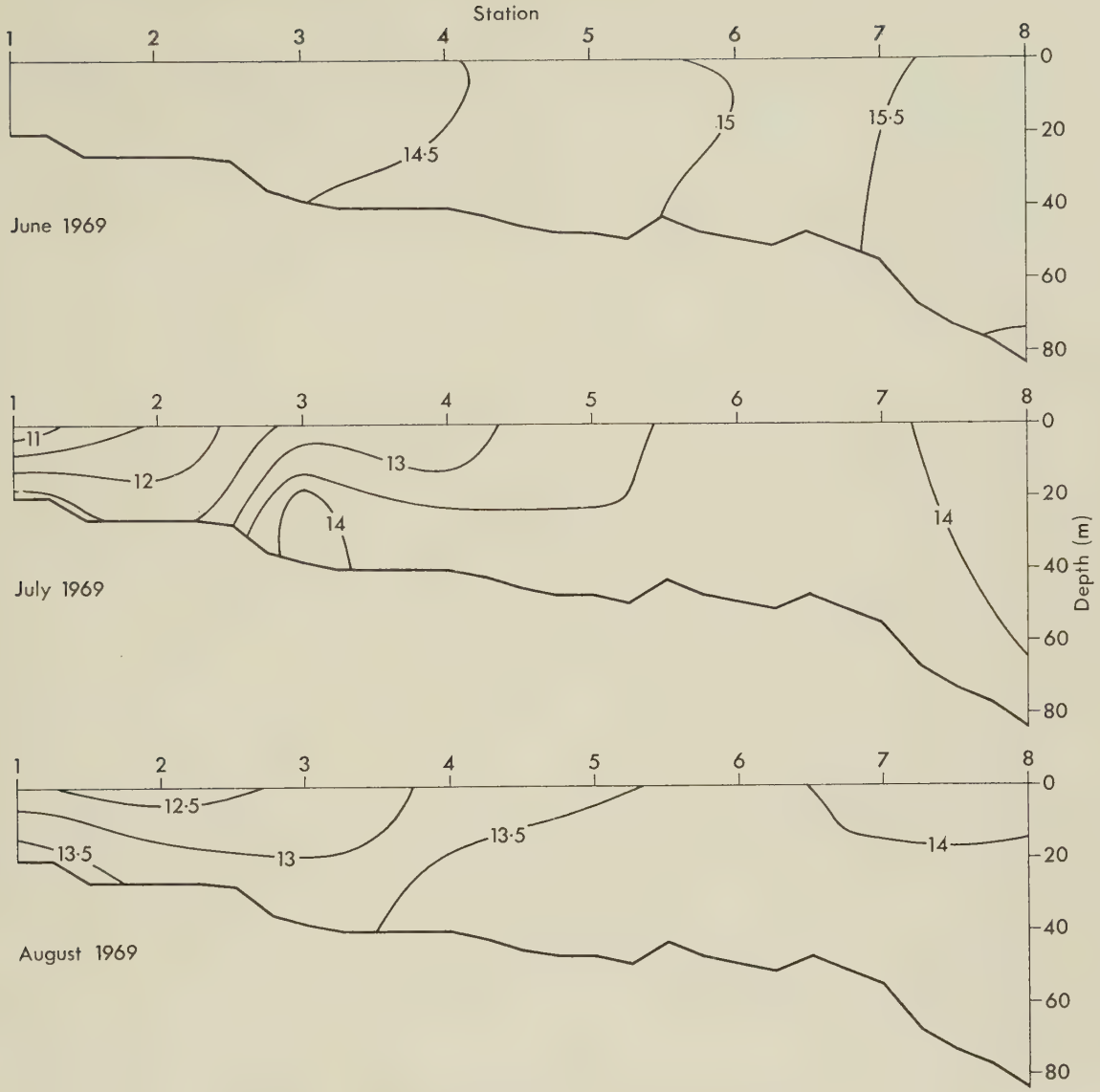

Fig. 30C: Temperature profiles from June to August 1969.

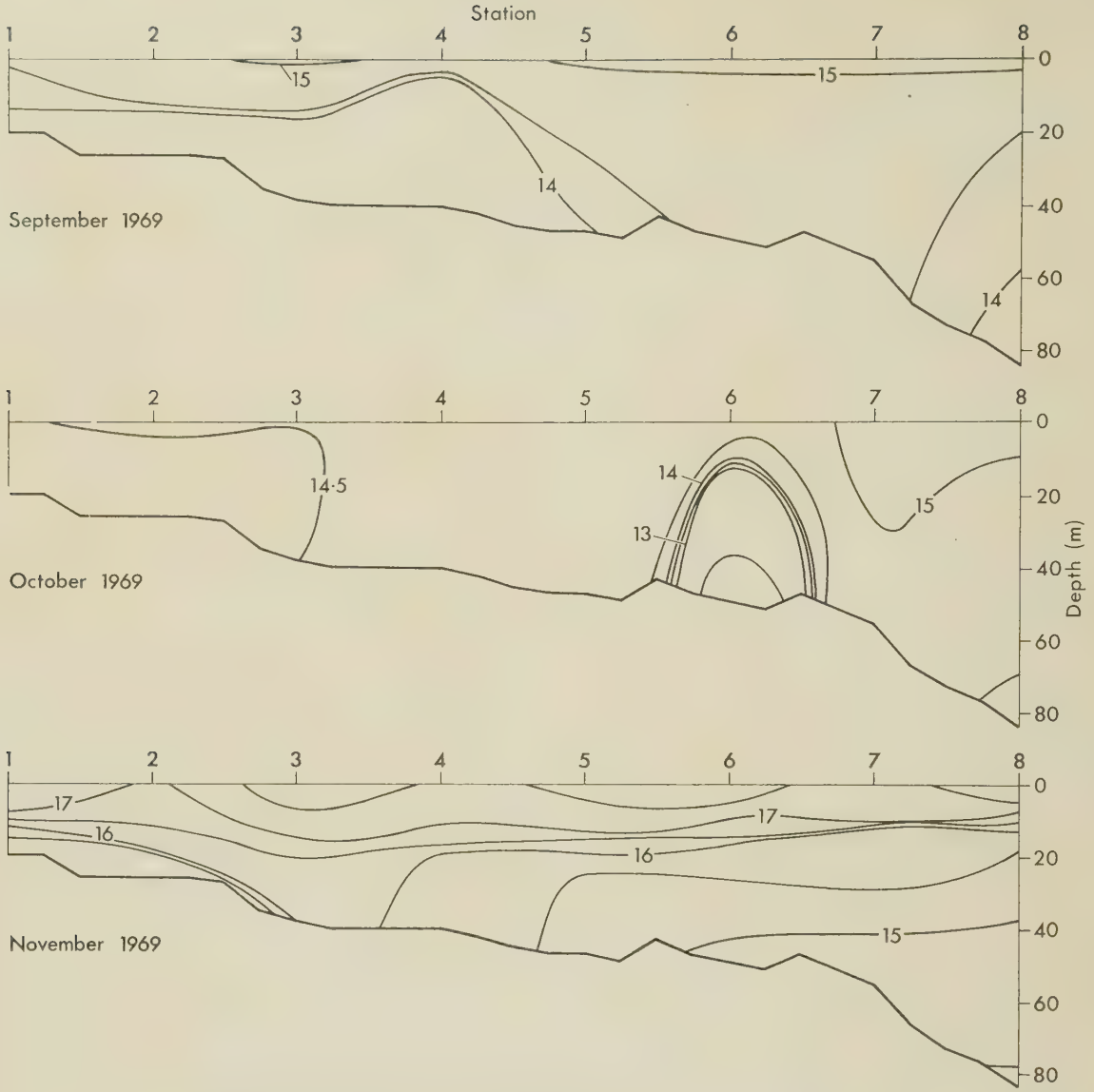

Fig. 30D: Temperature profiles from September to November 1969.

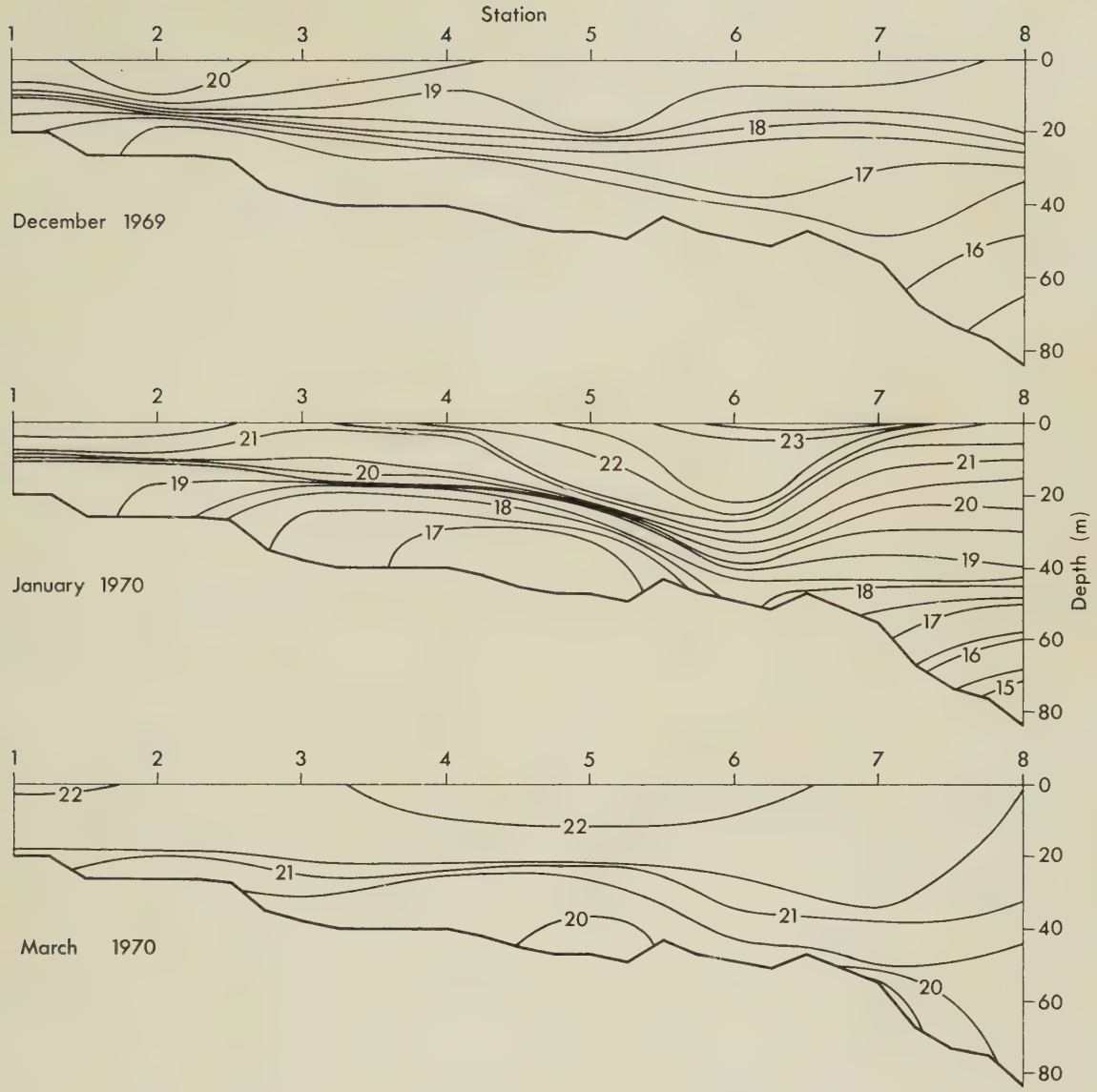

Fig. 30E: Temperature profiles for December 1969, January 1970, and March 1970.

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